A CONFIGURATION SELECTION PROCEDURE TO OPTIMISE THE COST OF LONGHAUL PULPWOOD TRANSPORT IN THE SOUTH AFRICAN FOREST INDUSTRY

by

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Declaration

I the undersigned hereby declare that the work contained in this thesis is my own original work and has not previously in its entirety or in part been submitted at any university for a degree.

Date: 14·11·95

Summary

The long distance road transport (longhaul) of pulpwood is typically the single largest cost associated with delivering pulpwood to a mill. The costs of owning and operating large truck-tractor trailer configurations, in turn, comprises the largest portion of this cost.

To optimise the costs associated with longhaul pulpwood transport, therefore, it is necessary to select the truck configuration which will minimise costs. Varying pulpwood lengths and density, and forest road conditions, negate the selection of a single truck configuration ideally suited to all operations.

This thesis places longhaul pulpwood transport in perspective and evolves a procedure to select the most appropriate truck configuration to optimise longhaul pulpwood transport costs in the South African forest industry.

Opsomming

Langafstand-padvervoer van pulphout is die grootste uitgawe verbonde aan die lewering van pulphout by 'n meul. Die koste verbonde aan eienaarskap en bedryf van groot vragmotorkombinasies vorm, daarenteen, die grootste gedeelte van hierdie uitgawes.

Om die koste verbonde aan langafstand-pulphoutvervoer te beperk, is dit dus eerstens noodsaaklik dat die regte keuse van die vragmotorkombinasie gemaak moet word. 'n Verskeidenheid van faktore, soos groot variasies in pulphoutlengtes en houtdigtheid en die toestand van die bospaaie, maak dit ontmoontlik om een vragmotorkombinasie te kies wat ideaal is vir alle omstandighede.

Dit is die doel van hierdie tesis om die langafstand-padvervoer van pulphout in perspektief te plaas, en om 'n prosedure te ontwikkel sodat die mees geskikte vragmotorkombinasie geselekteer kan word ten einde langafstand-pulphoutvervoer in die Suid-Afrikaanse bosbedryf op die mees koste effektiewe wyse aan te wend.

Acknowledgements

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Introduction

The long distance road transport of pulpwood is typically the single largest cost associated with delivering pulpwood to a mill. The costs of owning and operating large truck-tractor and trailer configurations, in turn, comprises the largest portion of this cost.

To optimise the costs associated with transporting pulpwood, therefore, it is necessary to select the truck configuration which will minimise costs. Speculation abounds within the South African forest industry as to which truck configurations are the most cost effective. This thesis, by way of an industry-wide survey, theoretical analysis, literature reviews and field trials, identifies objective evaluation criteria to determine the merits and limitations of the various pulpwood truck configurations. It then develops a rationale for selecting the most appropriate configuration for each operation.

The thesis is divided into six chapters:

- Chapter One places pulpwood transport in perspective and reviews the results of an industry-wide longhaul pulpwood transport survey.
- Chapter Two compares the economic performance of the various configurations and identifies those elements of a transport operation that have the greatest potential impact on transport costs.
- Chapter Three determines differences in manoeuvrability, stability and tractive ability between the three main configuration types.
- Chapter Four determines how pulpwood length and density influence the selection of the most appropriate configuration.
- Chapter Five identifies further configuration-specific limitations and compares the merits and limitations of the various configurations.
- Chapter Six concludes the thesis and discusses the development of a configuration selection procedure.

CHAPTER ONE

Pulpwood Transport in Perspective

1.1 Introduction

The transport of pulpwood from stump-to-mill can be divided into two distinct phases.

Primary transport denotes the infield movement (or ***extraction***) of the felled tree from the stump to the forest road, roadside or landing (collectively referred to as the primary landing). Timber may be extracted by animal, manually rolled or carried, dragged or carried by groundbased machines, or extracted partially or fully suspended by cables.

Secondary transport refers to the movement of timber from the primary landing to the processing plant. This may be accomplished by a single mode of transport using a single vehicle or may encompass a number of modes of transport (road, rail or water) and many vehicles.

Collectively primary and secondary transport, under South African conditions, may account for up to 55% of the mill-delivered cost of pulpwood. Secondary transport on its own may account for up to 45% of this cost (personal observation). Conway (1986) estimated that internationally total timber transport costs accounted for 50-60% of the mill-delivered cost and Williams and Nader (1993) estimated that under Canadian conditions secondary transport accounted for between 25-50% of the delivered wood cost.

Secondary transport in the South African pulpwood industry is often divided into two phases. A ***shorthaul***, denoting the transport of timber by road, over short distances, from the primary landing to either a centralised depot, a railhead and in some instances to the processing plant (if it is in close proximity); and a ***longhaul*** referring to the long distance transport of timber by road from a centralised depot (or primary landing if there is no shorthaul) to the processing plant. The longhaul transport of timber is often the single largest cost component in the timber production process accounting for up to 35% of the delivered cost of pulpwood.

The significance of longhaul transport is compounded by the specialised and demanding nature of the task. Large truck configurations operating at the extremes of dimension and payload regulations, encounter a wide variety of road surfaces, under varying conditions, hauling different products from many remote locations, to numerous markets, under all weather conditions and at all hours. In addition the task is further constrained by:

- The transport of a relatively heavy, low value product with a highly variable density.
- The transport of a product in one direction only with no or limited opportunities for a backhaul.
- Robust loading and offloading conditions.
- Highly visible mode of transport subject to biassed inspection and prosecution.

The cost and demands of longhaul transport are, unfortunately, often underestimated in the local forest industry. Formal research and education in forestry transport is largely non-existent and transport management is often relegated to uninformed hauliers, as transport, which largely occurs beyond the boundaries of the plantation, is not considered to be a core activity of foresters.

1.2 The South African Pulpwood Industry

A telephone survey of all pulpwood consuming mills revealed that approximately 8 497 562 tonnes of pulpwood will be consumed by 15 pulp, chip and board mills during 1995. This figure excludes mining timber and represents approximately half of the estimated total annual South African roundwood production (Department of Water Affairs and Forestry, 1995). Of this total 4 829 261 tonnes (57%) will enter the mills by road and 43% will enter by rail. Seventy-seven percent of all pulpwood will be consumed by six pulpmills, 16% by two chipmills and the remaining 7% by seven board mills. The differences in mode of transport for pulpwood entering the various pulpwood mills is shown in Table 1.1.

Table 1.1. Modes of transport into consuming pulpwood mills.

Mill type	Annual intake (tonnes)	Intake by road (%)	Intake by rail (%)
Pulp	6 567 562	57	43
Chip	1 351 000	39	61
Board	579 000	96	4
Total	8 497 562	57	43

1.3 The 1995 Longhaul Pulpwood Transport Survey

To gain an understanding of the extent and makeup of the pulpwood transport industry and to benchmark current technologies and practices, a detailed survey was conducted of hauliers operating within the two major forestry provinces of South Africa.

1.3.1 Method

A postal survey was conducted of all recognised longhaul pulpwood transporters operating in the KwaZulu-Natal and Eastern Transvaal Provinces, of South Africa, during the period March-April 1995. Recognised hauliers were defined as hauliers that consistently transported large annual tonnages of pulpwood (≥50 000 tonnes/annum) for the major forestry companies or cooperatives. They were identified with the assistance of forest company transport managers and from the results of previous surveys conducted by the author.

Pulpwood consumption by the 13 pulp, chip and board mills in the surveyed provinces accounted for 99.24% of total pulpwood consumption, making the survey area very representative of the industry. In addition, the survey area accounted for 98.65% of all timber entering pulpwood mills by road.

Thirteen survey questionnaires were sent to both independent transport contractors and forestry companies/cooperatives, who operated longhaul fleets. In most instances, survey questionnaires were sent to individual depots within a transport company to avoid assumptions being made by staff at a centralised level. All survey respondents were contacted by telephone to verify receipt of the questionnaires and to ensure their timeous return. Telephone conversations also enabled any misconceptions surrounding individual questions to be clarified.

The survey questionnaire was divided into four sections, relating to general company and operational data, loading, fleet data and transport management. There were 24 questions in total (see Appendix One for the questionnaire and Appendix Two for the results).

1.3.2 **Overview of survey results**

The survey results are discussed under two sections. An overview of the more relevant results is provided in this section to allow the reader to place the industry in perspective at a glance. Further results, more specific to detailed discussions, are also revealed in section 1.3.3.

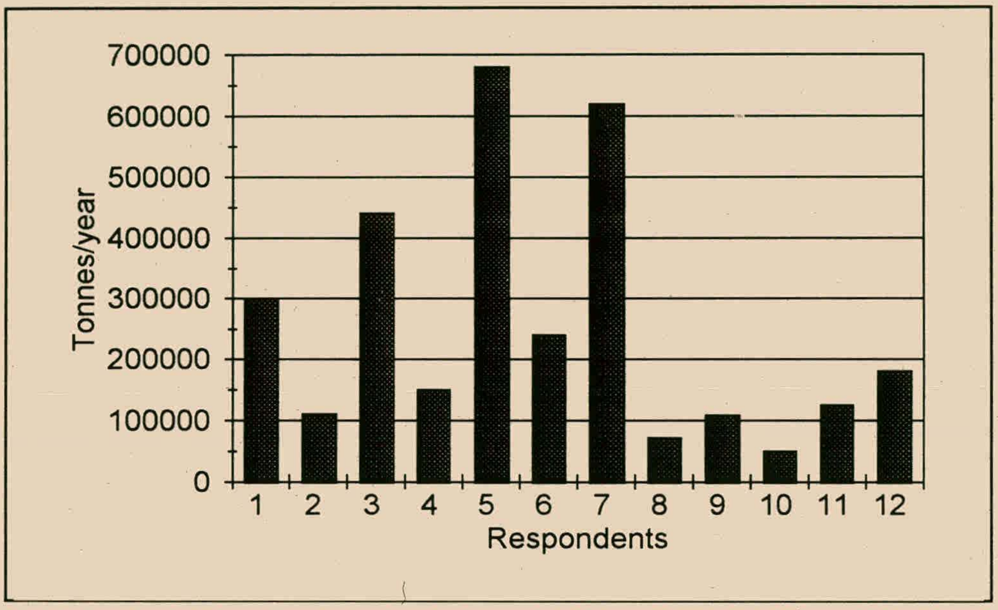
1.3.2.1 Response

Of the 13 survey questionnaires mailed, 13 were returned and 12 had been completed. One haulier no longer actively transported pulpwood. The survey respondents represented 10 individual companies. Seven were independent transport contractors, 2 were forest companies and 1 was a timber cooperative. Five of the contractors surveyed represented the timber transport section of a larger freight transport business.

1.3.2.2 Tonnages

The 12 survey respondents collectively transported 3 075 213 tonnes or approximately two thirds (64.55%) of pulpwood entering the 13 pulp, chip and board mills by road within the survey area. Figure 1.1 depicts the average annual tonnage transported by the individual respondents. The most pulpwood transported by an individual haulier was 681 313 tonnes. The least tonnes transported in a year was 50 000. Seven of the respondents transported between 100 000-300 000 tonnes of pulpwood per annum.

Figure 1.1. Average annual tonnes of pulpwood transported by individual respondents.



1.3.2.3 Species

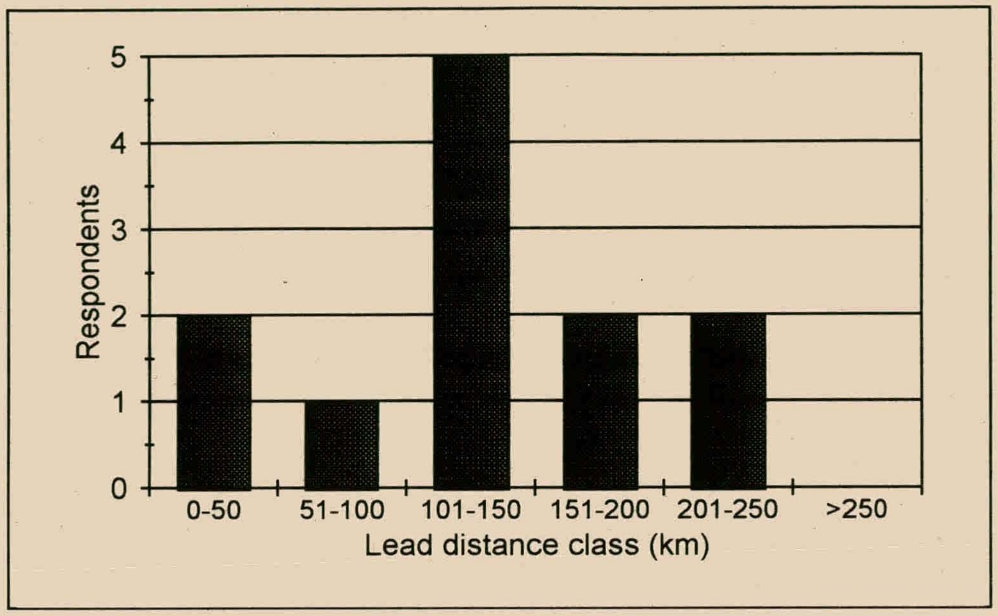
Hardwood species (Eucalypts and Acacias) accounted for 47.66% and softwood species (Pines) 52.34% of all pulpwood surveyed.

Eight of the respondents transported predominantly hardwoods (60-100% of pulpwood hauled). Four respondents transported mainly softwoods (90-100% of pulpwood hauled). See Figure 1.17 on page 19.

1.2.3.4 Lead distances

The weighted average transport lead (one-way) distance was 120.6 km. The shortest average lead distance was 29 km and the longest 230 km. The number of respondents per lead distance class is illustrated overleaf.

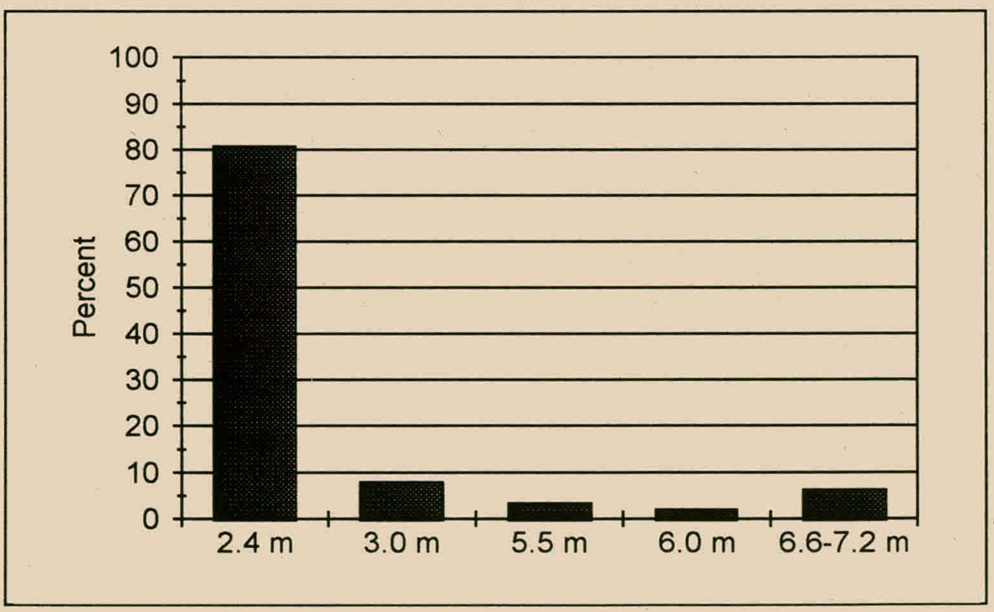
Figure 1.2. Number of respondents per lead distance class.



1.3.2.5 Pulpwood lengths transported

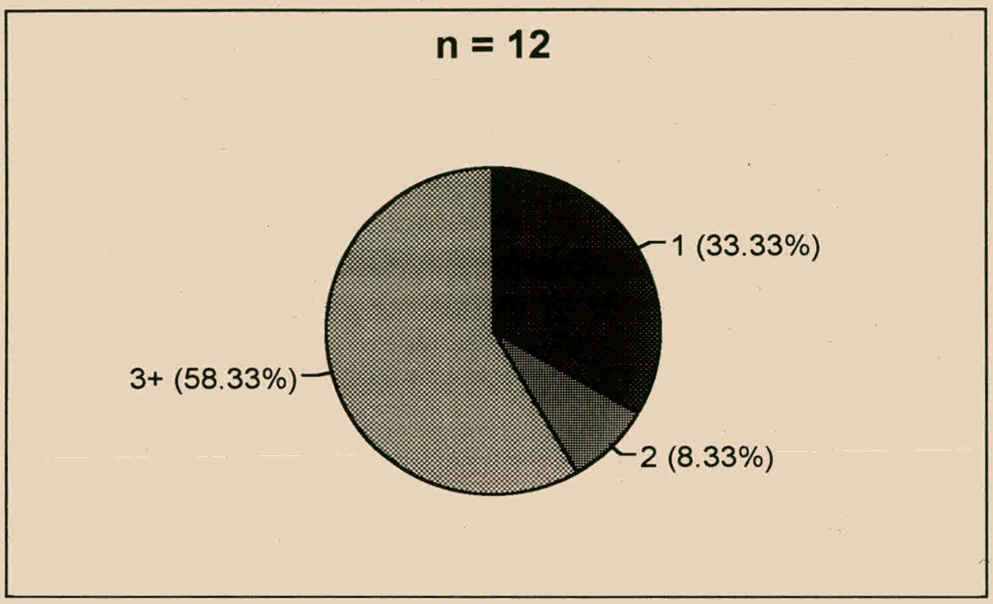
Most pulpwood surveyed (80.61%) was 2.4 m in length. The relative popularity of the remaining lengths is depicted in Figure 1.3.

Figure 1.3. Percentage popularity of pulpwood lengths transported.



1.3.2.6 Customers

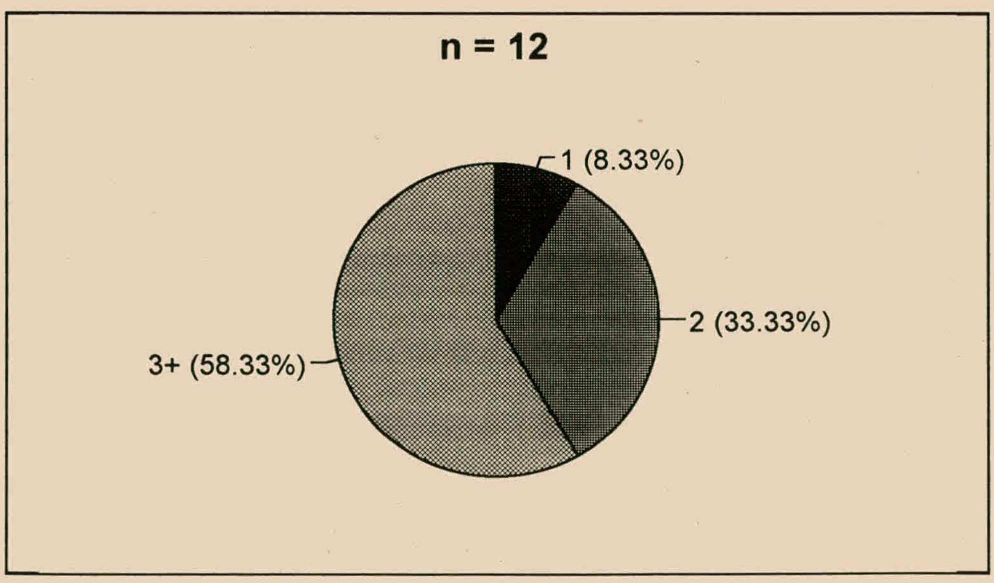
Figure 1.4. Percent of respondents delivering pulpwood for 1, 2 and 3 or more customers.



Seven respondents hauled pulpwood for 3 or more customers (forest companies, farmers, etc.). Of the 4 that transport for only 1 customer, 2 were forest company operations.

1.3.2.7 Markets

Figure 1.5. Percent of respondents delivering pulpwood to 1, 2 and 3 or more markets.



The majority of respondents delivered pulpwood to three or more markets. Only one respondent delivered to a single market.

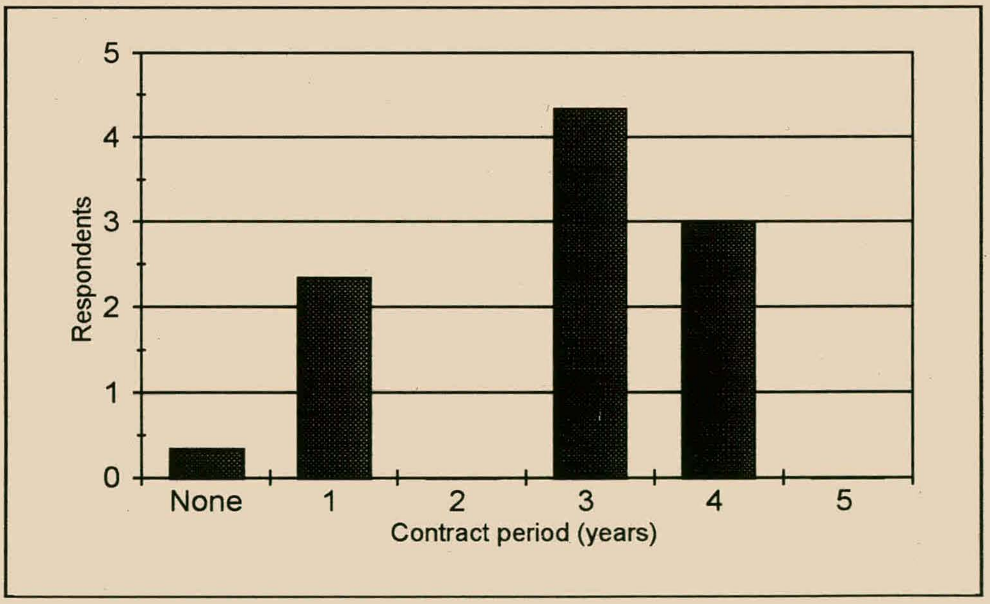
1.3.2.8 Products transported

Six respondents (50%) transported only pulpwood on their truck configurations. Two transported pulpwood and sugar cane and four pulpwood and other forest products (sawtimber and poles) on the same configurations.

1.3.2.9 Contracts

If the results of the two forest companies and the cooperative surveyed were excluded (as they haul own timber only), the majority of respondents (73.33%) had 3 or 4 year contracts. One respondent had contracts of varying lengths with different customers and hauled a small tonnage not under contract, hence the fractions of respondents and the "None" category shown in Figure 1.6.

Figure 1.6. Contract lengths



1.3.2.10 Payment

Most hauliers were paid on a R/tonne and a R/km basis.

1.3.2.11 Loading point

Almost half (48.66%) of all pulpwood was loaded at large, constructed, centralised depots. A further 43.31% was loaded at small informal depots and landings, and the remaining 8.01% was loaded at roadside.

1.3.2.12 Loading operation

Of all pulpwood surveyed 45.18% was loaded by machines owned by the respondents (own loaders). Loading performed by customers (companies timber was being loaded for) accounted for only 9.73% of pulpwood delivered. The remaining 45.09% was loaded by independent loading contractors.

1.3.2.13 Loader types

Figure 1.7. Percent of pulpwood surveyed loaded by different loader types

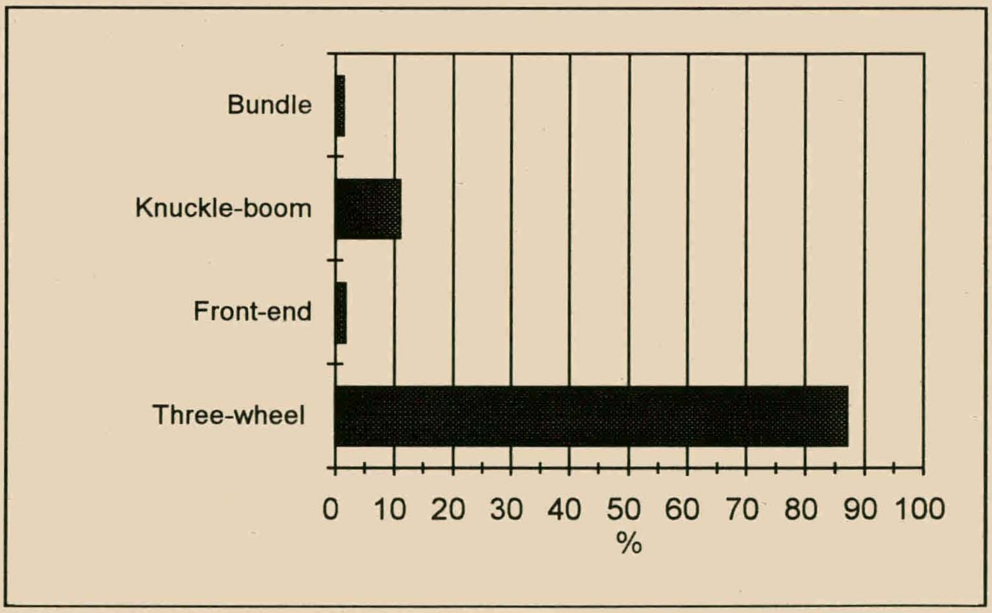


Figure 1.7 depicts the main loader types used (in terms of tonnes loaded). Most pulpwood (86.62%) was loaded by three-wheel (Bell Logger type) loaders. Knuckle-boom loaders accounted for only 10.53% of the loading.

1.3.2.14 Loaded timber orientation

All timber was longitudinally orientated (no crosswise loading was reported).

1.3.2.15 Payload

The weighted average payload was 35.18 tonnes. The lowest average payload was 26 tonnes and the highest legal payload 38 tonnes (see Figure 1.19 for average payload per respondent).

1.3.2.16 Tyres

Most respondents (8.3 or 69.17%) stated that they fitted mainly dual tyres to their trailers. One respondent (8.33%) fitted only super single tyres and the remainder single tyres. (Fractions of respondents are due to certain hauliers fitting more than one type of tyre).

1.3.2.17 Suspension systems

Most respondents (76.67%) stated they fitted mainly steel leaf spring suspensions to their trailers. Air-bag suspension systems were fitted by 13.33% and parabolic suspensions by the remainder.

1.3.2.18 On-board weigh scales

Fifty-nine trailers (28.09% of the 210 trailers surveyed) were fitted with on-board weigh scales. Three types of weigh scales were identified:

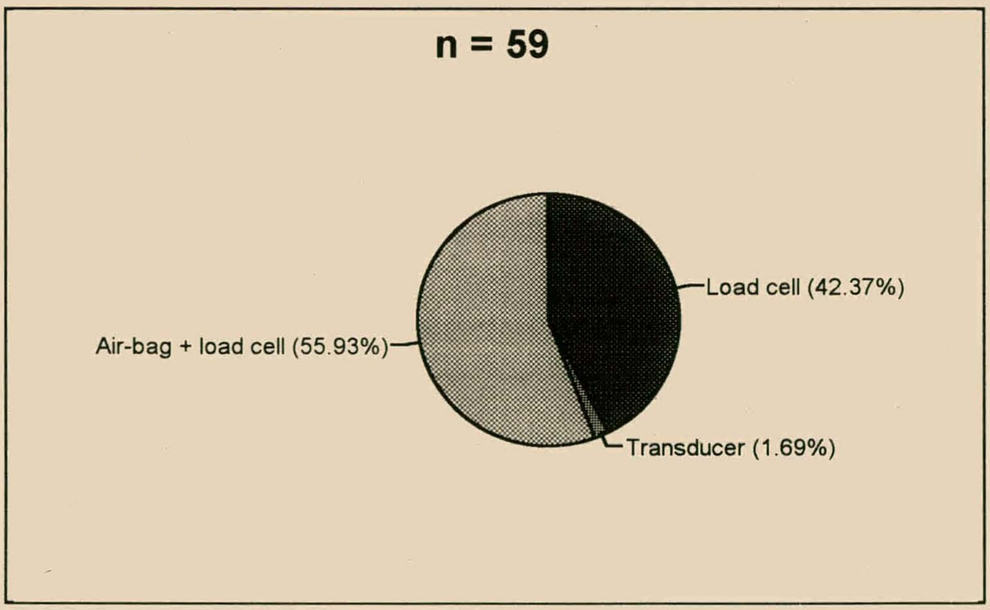
Load cells Solid steel bars mounted as an integral part of the vehicles structure that support the load at all times. Load weight is determined by strain gauges mounted on the load cell that measure the bend or shear of the load cell.

Transducers Also known as non-load bearing scales, they attach to a load bearing part of the vehicle and determine the load weight by measuring the amount of bending (deflection) in that part.

Air-bag scales Are found on trailers equipped with air-bag suspensions and measure the load-induced change in air pressure. Configurations fitted with air-bag suspension scales are usually combined with a load cell scale attached to the fifth wheel of the truck-tractor (Pottie, 1987 and Milroy, 1991).

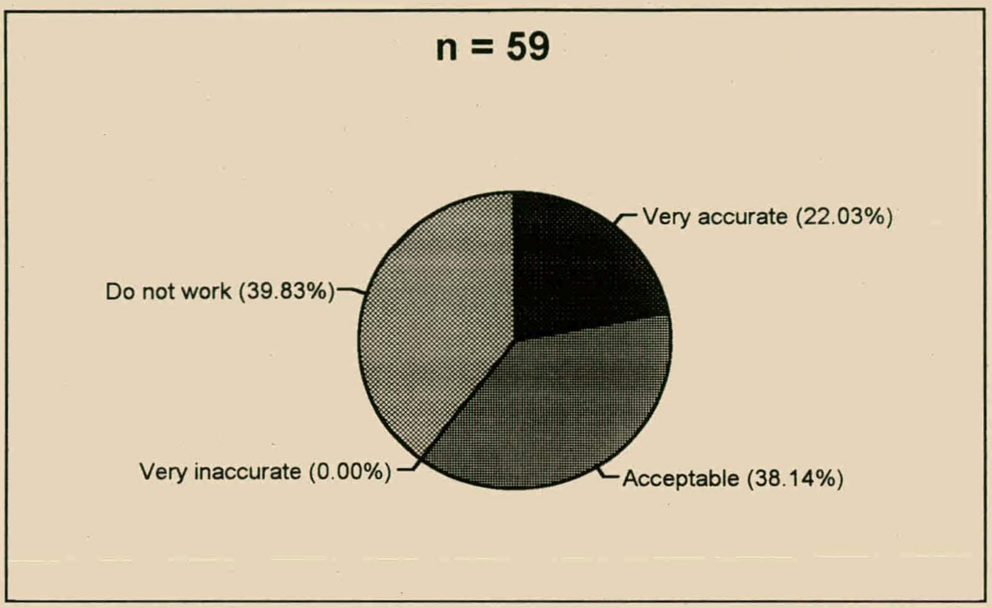
The popularity of the three scale types is illustrated below. Air-bag weigh scales (55.93%) and load cell scales (42.37%) were the most popular.

Figure 1.8. The popularity of on-board weigh scales.



The users' perception of the accuracy of the on-board weigh scales is illustrated in Figure 1.9.

Figure 1.9. Users' perception of the accuracy of on-board weigh scales.



Only 22.03% of the scales fitted were deemed to be very accurate, 38.14% had acceptable accuracies (or did the job) and 39.83% did not work. Only six (50%) of the respondents fitted on-board weigh scales.

1.3.2.19 Spillage prevention

To prevent the accidental spillage of pulpwood from the rear billet of trailers, 54 trailers (25.71%) were equipped with a tailboard, 72 (34.29%) used nets draped over the rearmost billet and 84 (40%) used strapping of bundles only, or took no precautions to prevent spillage.

1.3.2.20 Truck-tractor trailer configurations

A total of 210 configurations were surveyed. One hundred and eighty-six (88.57%) were interlink (B-train) configurations, 14 (6.67%) were semitrailer-drawbar trailer configurations and the remaining 10 (4.76%) were rigid truck and drawbar trailer configurations.

Fourteen different variations within the three configuration types were identified. The popularity of these configurations is tabled overleaf.

Table 1.2 The popularity of pulpwood configurations.

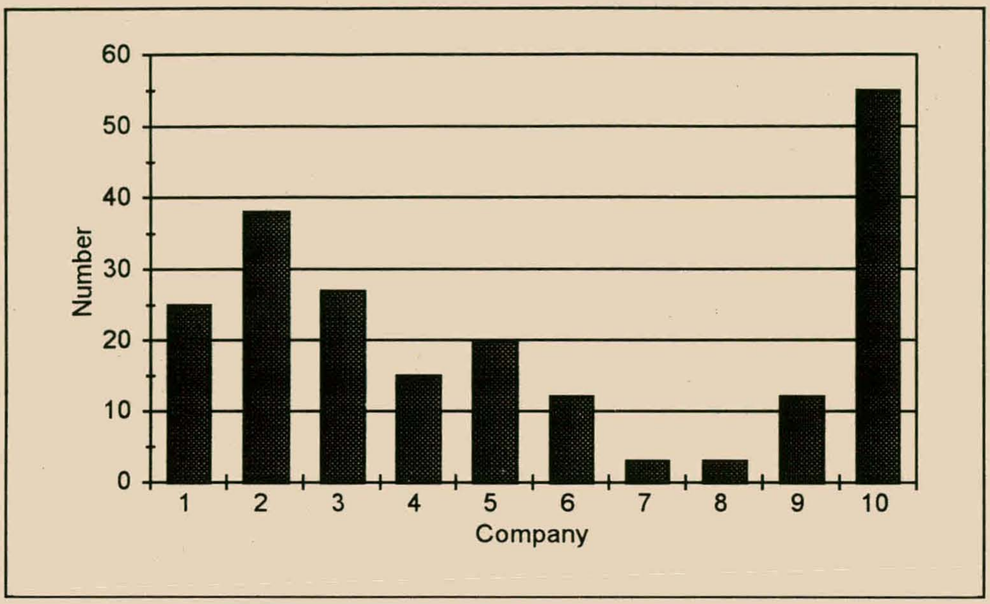
Configuration	Code*	Number	% of config.	% of total	Ranking
Interlink configurations					
	I20-1222-3+3	68	36.56	32.38	1
	I22-1222-3+3	18	9.68	8.57	3
	I22-1232-3+3	13	6.99	6.19	5
	I22-1231-4+2	1	0.54	0.48	10
	I22-1222-3+4	13	6.99	6.19	5
	I22-1232-3+4	16	8.60	7.62	4
	I22-1223-2+4	3	1.61	1.43	8
	I22-1222-2+5	41	22.04	19.52	2
	I22-1232-2+5	13	6.99	6.19	5
Semitrailer-drawbar trailer configurations					
	SD20-12211-4+2	2	14.29	0.95	9
	SD22-12211-4+2	12	85.71	5.71	6
Rigid truck-drawbar trailer configurations					
	RD20-1212-3+3	8	80.00	3.81	7
	RD22-1222-2+4	1	10.00	0.48	10
	RD22-1222-2+5	1	10.00	0.48	10

* *The key to the configuration code is as follows:*

I, SD and RD denote the configuration type (interlink, semi-drawbar and rigid-drawbar); 20 and 22 denote the total configuration length in metres; 1232 describes the axle unit layout of the configuration from steering axle to rear axle eg. single-tandem-tridem-tandem; and 3+3 denotes the number of 2.4 m pulpwood billets per unit of the trailer or configuration.

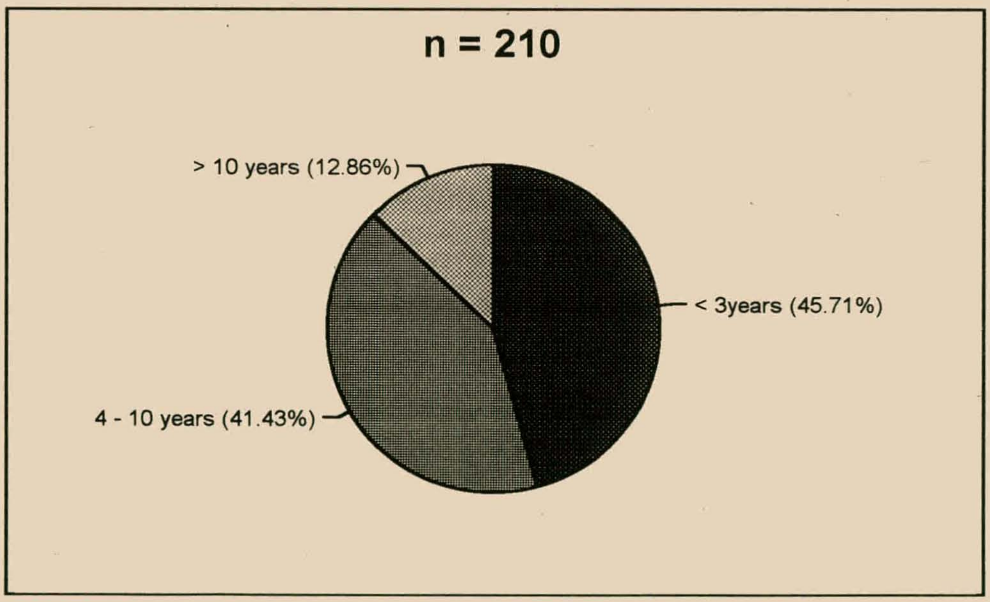
Forty percent of all configurations surveyed were capable of carrying seven 2.4 m billets, 21.9% of the trailers had a tridem axle unit and 62.38% (131 units) were 22 m long.

Figure 1.10. The number of configurations per surveyed company.



1.3.2.21 Trailer ages

Figure 1.11. A percentage breakdown of the trailer ages surveyed.



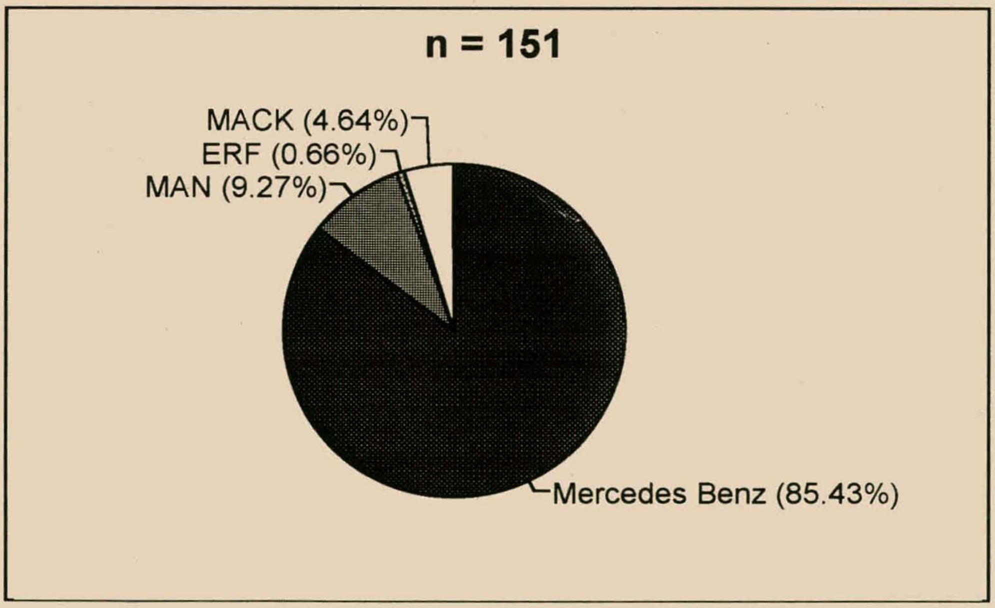
Trailer ages were divided into three categories. The category of trailers less than 3 years old (constructed during 1992/93/94) reflected trailers that were constructed to the new dimension regulations of the Road Traffic Act (Act No 29 of 1989). The 4-10 year category reflects trailers constructed to the old regulations but may have been modified to the new regulations. The greater than 10 years category reflects old trailers constructed to old regulations, using dated materials and technologies.

Ninety-six (45.71%) of the trailers surveyed had been constructed since 1992. The remainder were older than 4 years and had initially been constructed to the requirements of the old dimension regulations.

1.3.2.22 Truck-tractors

One hundred and fifty-one truck tractors were surveyed. Mercedes Benz was the most popular manufacturer accounting for 85.43% of all models. The popularity of the remaining manufacturers is shown in Figure 1.12.

Figure 1.12. Popularity of truck-tractors used in the longhaul pulpwood industry.

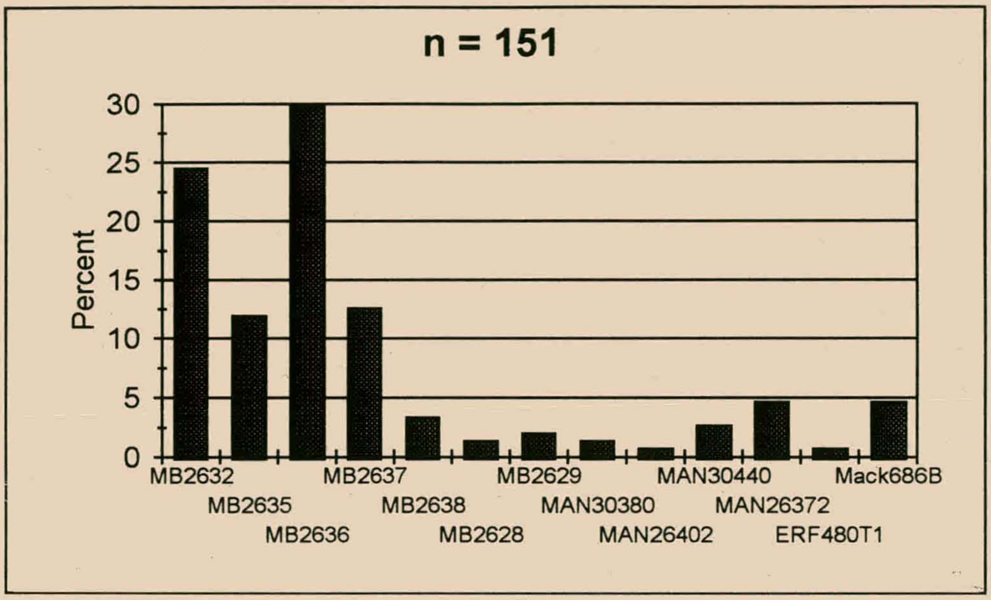


Eight of the respondents showed loyalty to only 1 manufacturer. Three operated truck-tractors from 2 manufacturers and 1 truck-tractors from 3 manufacturers.

The most popular truck-tractor model was the Mercedes Benz 2636 (29.8%), followed by the

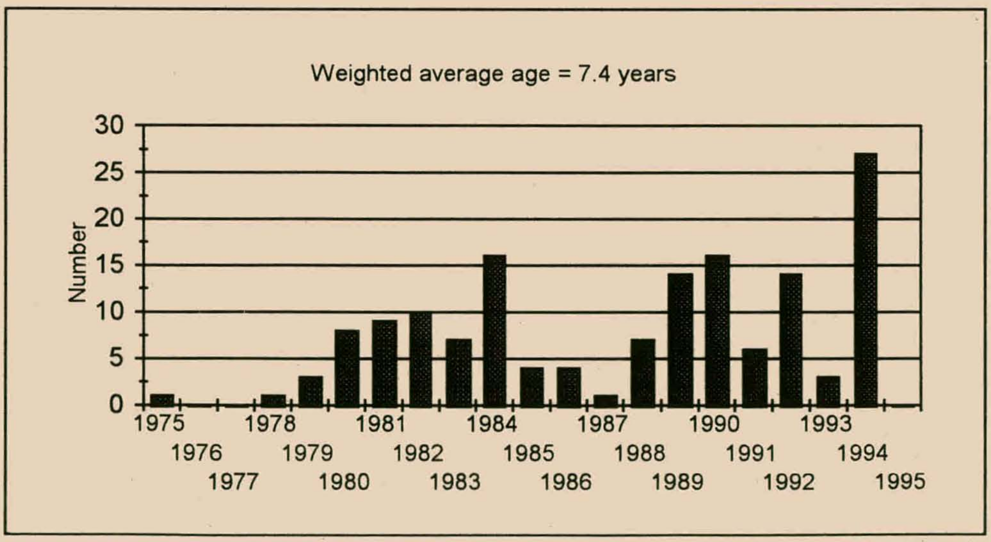
Mercedes Benz 2632 (24.5%) and Mercedes Benz 2637 (12.58%) models. The popularity of the remaining models is shown below.

Figure 1.13. The popularity of truck-tractor models surveyed.



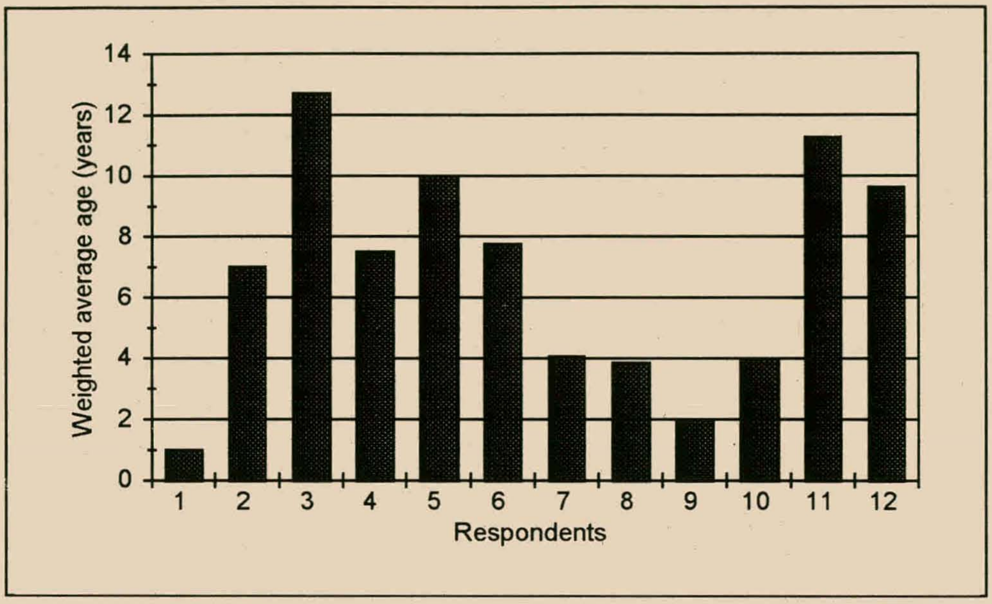
Two respondents had only one model of truck. Five operated 2 models, three operated 3 models and the remaining two operated 4 models. The age class distribution of the truck-tractors surveyed is shown in Figure 1.14.

Figure 1.14. Age class distribution of truck-tractors surveyed.



The weighted average age of all truck-tractors was 7.4 years. Figure 1.15 depicts the weighted truck-tractor age per respondent.

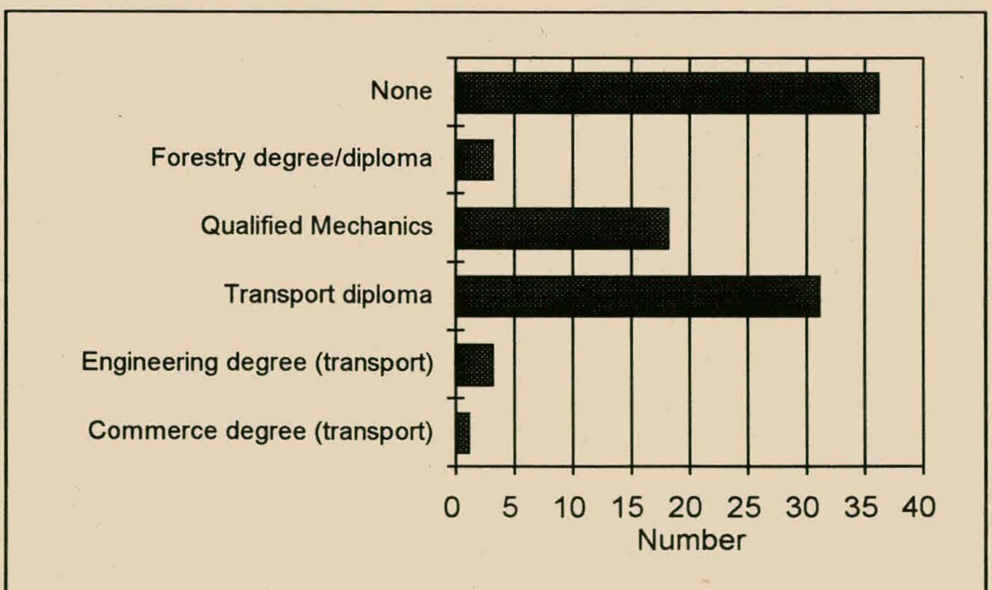
Figure 1.15. The weighted truck-tractor age class per respondent.



The lowest weighted age was 1 year and the highest 12.76 years.

1.3.2.23 Transport manager qualifications

Figure 1.16. Qualifications of operational transport managers.



There were 92 operational transport managers surveyed. Thirty-six (39.13%) had qualified by experience and had no formal background in transport, 31 (33.70%) had received a certificate or diploma in transport management and 18 (19.57%) of the managers had a mechanical background.

1.3.3 **Discussion**

1.3.3.1 Respondents

Survey questionnaires were sent to all large, recognised longhaul pulpwood transporters. A number of smaller operators who occasionally transported pulpwood or transported small tonnages (10 000-20 000 tonnes/annum), were also identified. These operators typically had less than three configurations, most of which were acquired secondhand from recognised hauliers. Collectively they transported an estimated 100 000 tonnes of pulpwood per year. As these informal operators were often not dedicated pulpwood transporters, used dated and depreciated equipment and individually hauled small volumes, it was decided to exclude them from the survey.

1.3.3.2 Tonnages

The survey accounted for 64.55% of all pulpwood entering the consuming mills, in the survey area, by road. If one were to add the estimated 100 000 tonnes from the informal unsurveyed longhaul transporters to the surveyed tonnage, approximately 67% of all pulpwood entered mills by way of longhaul truck configurations. This would imply that the remaining third entered mills by smaller trucks and tractor-trailer combinations.

1.3.3.3 Species

Most respondents transported either predominantly hardwoods or softwoods. The hardwood/softwood split transported per respondent is shown in Figure 1.17. A single wood type accounted for 90% or more of timber transported for seven respondents.

Figure 1.17 The percentage hardwood/softwood transported per respondent.

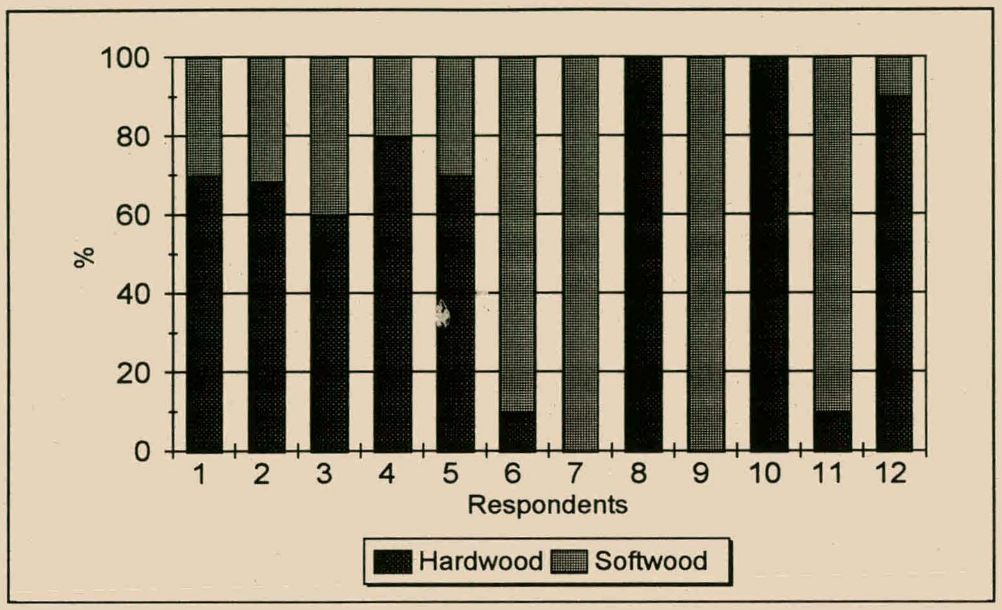
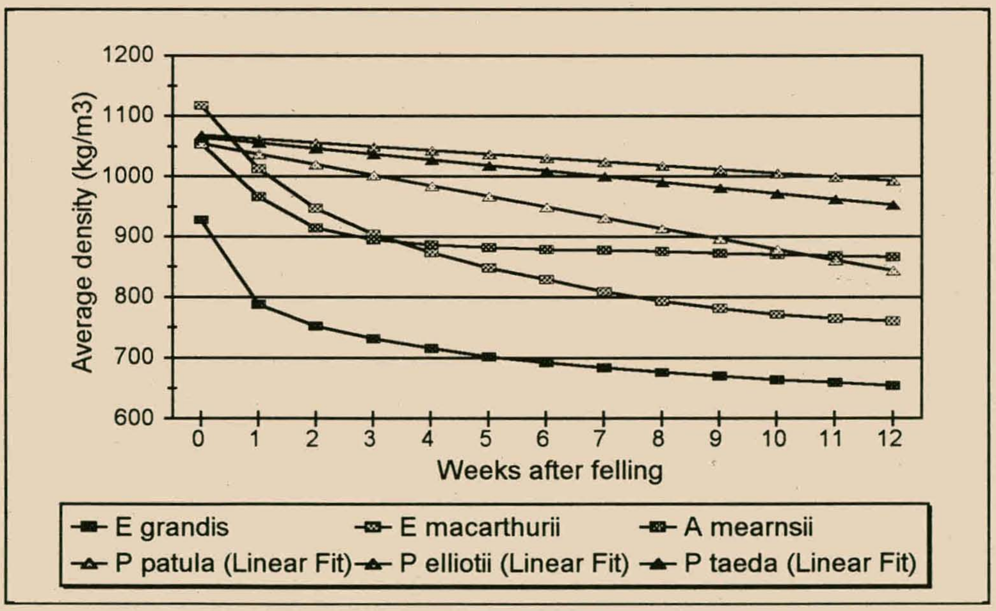


Figure 1.18 compares the weight loss after felling for three hardwood species (squares - curved lines) with three softwood species (triangles - straight lines).

Figure 1.18. Weight loss after felling for hardwoods and softwoods.



Eucalyptus grandis is the most common hardwood species and *Pinus patula* the most common softwood species. From the graph it is noticeable that the average density of the three hardwood species lie predominantly below that of the softwood species. The weight loss of the hardwood species is also more pronounced than that of the softwood species (particularly in the first week or two after felling). Of all the species grown in South Africa, *E. grandis* has the lowest average density and *Pinus elliotii* the highest (for the period depicted in the Figure). It should be noted that the weight loss curves reflect the state of conversion at the mill weighbridge (softwood species undebarked, hardwoods debarked). The average density difference between *E. grandis* and *P. patula* over the 12 week period is 232.8 kg/m^3. The average density difference between the selected hardwood and softwood species, over the period, is 169.72 kg/m^3. (Schönau, 1989 and Stöhr, 1983)

The age-after-felling pulpwood mill requirements vary by product, by species and by mill. Typical requirements for the bulk of the pulpwood ranges from 3-26 weeks (or less than 6 months old). It is, however, speculated that the vast majority of pulpwood (with the possible exception of *Acacia mearnsii*) enters pulpwood mills within 12 weeks (3 months) after felling.

From the above discussion it would appear that the differences in density between hardwoods and softwoods would exact different requirements from the truck configurations used to transport the various pulpwood species. Truck configurations specialising in hardwood transport (particularly *E. grandis*) would require a larger bulk volume to ensure that maximum payloads are achievable. On the other hand, configurations specialising in softwoods would not require an excessive volume, as densities allow maximum payloads to be easily achieved. This discussion is continued in detail in Chapter Four.

1.3.3.4 Pulpwood lengths

The results of the lengths transported indicate that despite the tendency towards longer lengths, 2.4 m lengths still predominate. The recent moves to 3.0, 5.5 and 6.0 metre lengths still have to gain wider acceptance and at present only 242 000 tonnes (7.87%) and 162 197 tonnes (5.27%) are being transported as 3.0 m and 5.5-6.0 m lengths respectively. Only seven configurations (3.33%) have been modified to carry 5.5-6.0 m lengths.

1.3.3.5 Customers and markets

To limit exposure to mill stoppages, cyclical demand and constrained supply most respondents supply timber for a number of customers and to numerous markets. It is interesting to note that only 175 000 tonnes (5.69%) of all pulpwood is transported by company owned fleets. A further 180 000 tonnes (5.85%) is transported by a large timber cooperative on behalf of its members. Most pulpwood (88.46%) is transported by large independent transport contractors.

1.3.3.6 Contracts

When excluding the results of the two forestry companies and cooperative from the survey, the volumes of pulpwood transported not under contract, are insignificant. This would suggest that the relationships between the contractors and the forest companies are highly formalised and that the contractors operate in a reasonably stable environment. The longer term 3-4 year contracts also facilitate investment in new equipment and encourages the introduction of new technologies leading to increased efficiencies.

1.3.3.7 Loading point

The point of loading in the plantation determines the distance to be travelled on forest roads and the likely condition of these roads. The closer loading is to the primary landing (roadside or landing), the further into the plantation the truck must travel and the greater the likelihood of encountering poor roads and unfavourable operating conditions.

Large centralised depots are normally sited on roads of main or secondary importance and require little "off-highway" travel to be accessed. For harvested timber to reach these depots a shorthaul operation is necessary. Almost half (48.66%) of all surveyed pulpwood was loaded at large depots, indicating that a shorthaul operation forms a significant component of secondary transport.

A further 43.31% of pulpwood was loaded deeper into the plantation at small informal depots and landings. To access these loading sites requires longer off-highway travel distances on poorer quality forest roads. Harvested timber is also often shorthauled over shorter distances to reach these sites.

1.3.3.8 Loading operation

With the exception of about 300 000 tonnes (9.73%) of pulpwood loaded by equipment belonging to the customer, equal amounts (approximately 45%) are loaded by the hauliers themselves (own loaders) and by contract loaders.

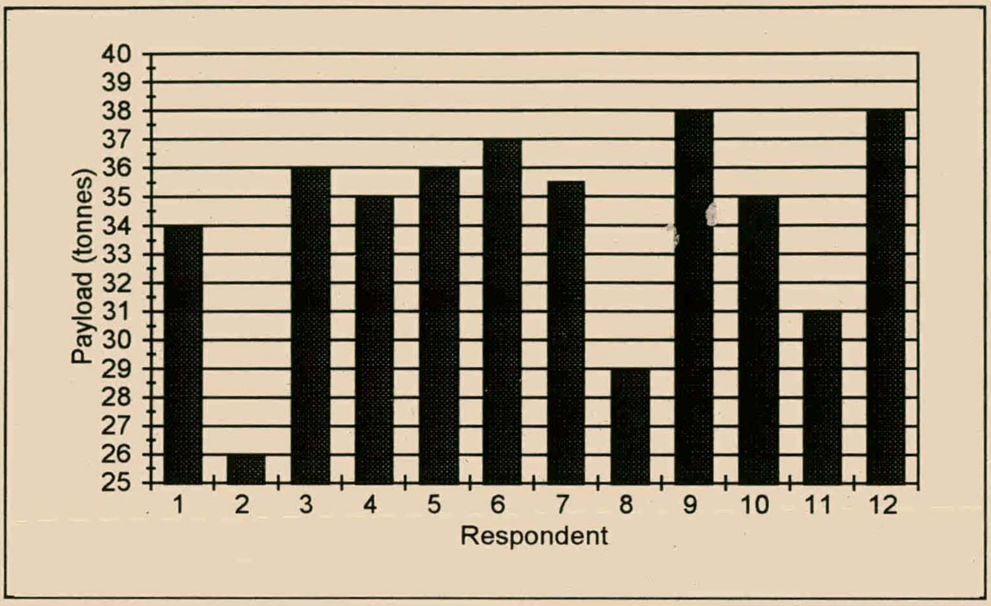
Loading timber with own loaders increases flexibility at the possible expense of utilisation. Contract loaders, on the other hand, have the ability to focus on one task and the potential to increase utilisation (and reduce costs) by operating for more than one haulier. The task of management to coordinate loading and scheduling, however, increases with the use of independent contract loaders. As few stump-to-mill contracts exist, the addition of another contractor in the harvesting-shorthaul-loading-transport chain can imply that the functioning of up to four independent contractors has to be coordinated and controlled from felling to delivery.

Although three-wheel loaders are the most popular loader type, many customers (particularly large forest companies) are beginning to express concern over the unnecessary damage to road and depot surfaces caused by these machines. This concern, coupled to the cost of moving these loaders between loading sites, is likely to encourage the greater use of truck and tractor mounted knuckle-boom loaders.

1.3.3.9 Payload

Only two of the 12 respondents operated at the current legal benchmark payload of 38 tonnes. Figure 1.19 indicates that most respondents (7) operate at between 34-37 tonne average payloads. The importance of payload on transport costs is discussed in Chapter Two.

Figure 1.19. Average payload per respondent.



1.3.3.10 On-board weigh scales

On-board weigh scales were first fitted to a South African pulpwood configuration in 1992 (Grafton, 1992 and personal observation). Transport contractors were encouraged to fit these devices at the insistence of forest companies (who wanted to consistently maximise payloads) and in reaction to the stiffer overloading penalties proposed by the then threatening Road Transport Quality System (RTQS). Many operators were initially sceptical of the accuracy and cost effectiveness of these on-board scales, a perception that may have been justified by the survey responses to their accuracies (refer to Figure 1.9). One respondent representing 22 configurations equipped with load cells felt they "Do not work".

International research (Pottie, 1987; Shaffer *et al*, 1987; Phillips, 1989 and Jones, 1993) regarding on-board weigh scales has shown that:

- Load cell scales are the most accurate.
- The accuracy of load cell scales varies widely, but that generally accuracies of less than 1% of gross combination mass (GCM) are achievable.

- There was no significant difference in performance between recognised load cell brands.
- The method of fitment, maintenance of scales, ground conditions at weighing and driver experience affected the accuracy of on-board weighing systems.

The response that load cell weigh scales do not work may thus suggest the use of an unproven brand or poor installation rather than the use of a poor concept. Further, a response that only 65% of air-bag weigh scales produced only acceptable results may indicate the selection of a less accurate on-board weighing system. A summary of weigh scale accuracy responses is tabled below.

Table 1.3 The accuracy responses to on-board weigh scales.

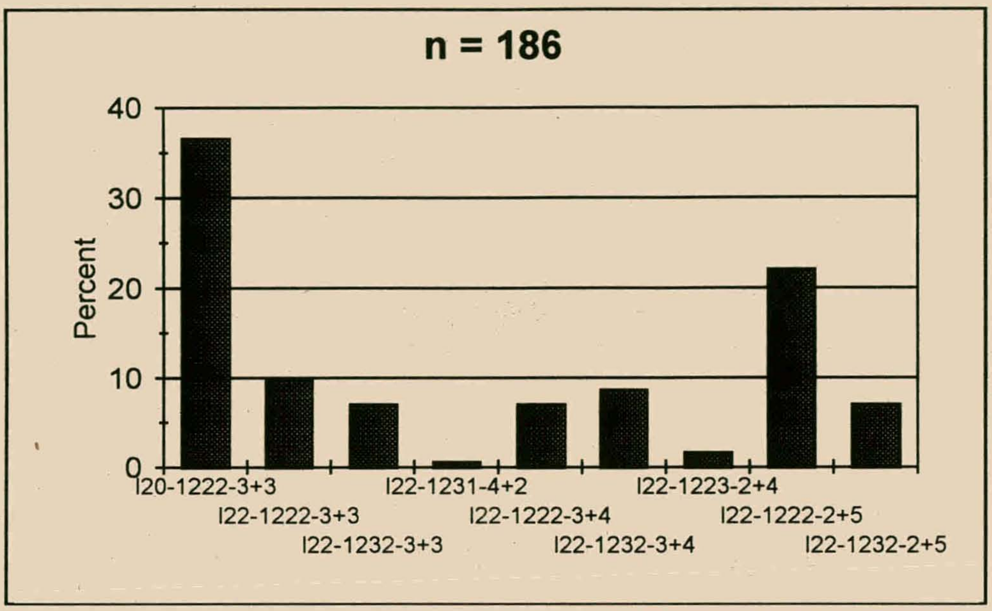
Type	Number	Very accurate	Acceptable	Very inaccurate	Do not work
Load cell	25	3	-	-	22
Transducer	1	-	1	-	-
Air-bag	33	10	21.5*	-	1.5*

* *One respondent felt that the linkage between the air-bag scales and the fifth wheel load cell created problems, causing the system to give both acceptable results when working and to not working at all.*

1.3.3.11 Configurations

The interlink continued to be the most popular configuration type accounting for 88.57% of all configurations. Informal surveys conducted by the author revealed that it was the most popular configuration type in 1993 and 1994 (Morkel, 1994). Despite its popularity, a considerable degree of variation within the configuration type was evident. (see Table 1.2 and Figure 1.20 overleaf).

Figure 1.20. Variations within the interlink configuration type.



Nine variations of interlink were identified. Of concern was the high proportion of interlinks that were still 20 m in length (36.56%). Payload losses of at least 2 tonnes are incurred by operating configurations constructed to the old regulations (due to the restrictions of the bridge formula).

The respondent that had the largest fleet of trailers (see Figure 1.10) serviced many small and often remote customers. To allow sufficient time for loading (often manual loading), trailers have to be left with the customers for several days. This practice necessitates such a large (and largely dated) fleet.

As a point of interest, it is worthwhile noting that all respondents that have configurations capable of carrying seven 2.4 m billets, transport predominantly (60-100%) hardwoods. This appears to confirm the thinking that each wood type has an appropriate configuration (refer to section 1.3.3.3 and Chapter Four).

1.3.3.12 Truck-tractors

Of the 13 truck-tractor models surveyed (see Figure 1.13) only 6 are still in production. In terms of numbers of trucks only 49 (32.45%) thus reflect the latest locally available truck-tractor technology. The manufacture of the most common model (MB 2636) ceased production in 1990 and that of the second most common (MB 2632) in 1983. Despite these statistics it is encouraging to note that the average age of truck-tractors in the pulpwood industry (7.4 years) is significantly below the estimate for the country of between 12-14 years. Reasons stated for the ageing nature of truck fleets in South Africa are the combined affects of sanctions, the local content policy and inflation. Collectively these factors have pushed the cost of acquiring new heavy vehicles to impractical heights (Ebersohn, 1995).

A closer assessment of the weighted average truck age per respondent (refer to Figure 1.15) reveals that operators broadly fall (willingly or unwillingly) into one of two fleet age categories. Those operating ***new*** fleets (weighted age 4 or less years) and those operating ***dated*** fleets (weighted age in excess of 7 years). Five respondents fall into the new and 7 into the dated categories. No correlation could be found between haulier size (tonnes moved) and category.

It should be noted that the results of the respondent with the most dated fleet (12.76 years) may be misleading, as truck-tractors are remanufactured at the end of their economic life, effectively doubling the life of each unit. The replacement cost of new truck-tractors may have warranted this approach, but the technologies associated with the truck-tractors remain largely unchanged and are thus still dated.

The absence (or ignoring) of appropriate rate setting and escalation policies to allow for sufficient capital recovery to replace ageing equipment, and an increasingly competitive market have made it difficult for many of the respondents to acquire new trucks without demanding unacceptably high rate escalations. The lure of retaining depreciated vehicles to make use of the "window" (following the depreciation period), in which operators can offer competitive rates by undercutting prices, may have contributed to this dilemma. In the face of rising maintenance costs, declining availability and productivity, and technical obsolecense, however, these operators are eventually forced from the market as they cannot maintain either the rates or reliability of service.

Operators that have managed to retain new fleets through replacement cost accounting and by taking advantage of the benefits of reduced tare mass, increased fuel efficiency and the reliability of new truck-tractors, have been able to keep up with technology and immediately pass technology induced savings on to the customer. Tare mass reductions in excess of 1 tonne and fuel consumption improvements of 20% are possible between new and dated trucks. It has been determined that transport costs show a high sensitivity to tare mass (payload) and medium sensitivity to fuel consumption and purchase price (see Chapter Two). Provided that the combined effect of lighter tare mass (or increased payload) and improved fuel consumption outweigh the effect of increased purchase price, it should be possible to acquire and retain new equipment and still remain competitive. The fact that five respondents fall into the new category may add weight to this argument.

1.3.3.13 Manager qualifications

The demands imposed by long distance pulpwood transport require a comprehensive understanding of transport and a sound knowledge of forestry to reduce the delivered cost of pulpwood to profitable levels. On the one hand, an understanding of the product, harvesting systems, road standards, road construction and maintenance practices needs to be combined with the limitations of the various configurations and the impact of the operating conditions on transport costs on the other, to select the most appropriate configuration for each operation.

Only 38.04% of transport managers surveyed had a recognised transport background. Significantly fewer (3.26%) had a forestry background. Most managers (58.7%) had no formal background in either transport or forestry. The number of managers with both forestry and transport qualifications could not be determined from the survey results as the formal background of those managers with diploma qualifications was not surveyed. Notwithstanding this fact, personal observation and communication have shown that very few transport managers have both a formal qualification in forestry and transport.

1.4 Conclusion

Fifteen pulp, chip and board mills in South Africa plan to consume approximately 8.5 million tonnes of pulpwood during 1995. Fifty-seven percent of this tonnage will enter mills by road and 43% will enter by rail.

A longhaul pulpwood transport survey of the KwaZulu-Natal and Eastern Transvaal provinces, which account for 99.25% of all pulpwood consumption, revealed that the longhaul transport of pulpwood on large truck configurations, accounted for approximately two thirds (or 3.175 million tonnes) of all pulpwood entering consuming mills by road.

All pulpwood was delivered in short lengths (2.4-7.2 m), by primarily large independent transport contractors. Almost half of all timber (48.66%) was loaded at large constructed centralised depots. A further 43.31% was loaded at small informal depots or landings. These figures suggest that the secondary transport of pulpwood in South Africa typically includes a shorthaul operation. Equal amounts of pulpwood were loaded by transport contractors and independent loading contractors (approximately 45%). Average longhaul lead distance was found to be 120.6 km.

The interlink (B-train) configuration type was the most common configuration accounting 88.57% of all those surveyed. Average payload for the industry was 35.18 tonnes with maximum legal payloads of 38 tonnes being achieved.

Only 38.04% of all transport managers surveyed had a recognised qualification in transport.

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CHAPTER TWO

Economic Comparison of Pulpwood Truck Configurations

2.1 Introduction

As part of the process to develop a configuration selection procedure to optimise the costs of long distance pulpwood transport, numerous truck configurations were subjected to an economic analysis and comparison, using the Logtran II transport costing programme, developed by the Council for Scientific and Industrial Research (CSIR). The approach adopted in the comparison largely followed that of the New Zealand Logging Industry Research Organization (Jones, 1993).

Input data for the computer programme (fixed, variable and operational data) were obtained from manufacturers and hauliers and average operating conditions were extracted from the results of the transport survey (discussed in Chapter One). The R/tonne cost for each configuration was then determined, using the programme, and ranked according to its relative performance.

The primary objectives of the theoretical comparison were twofold:

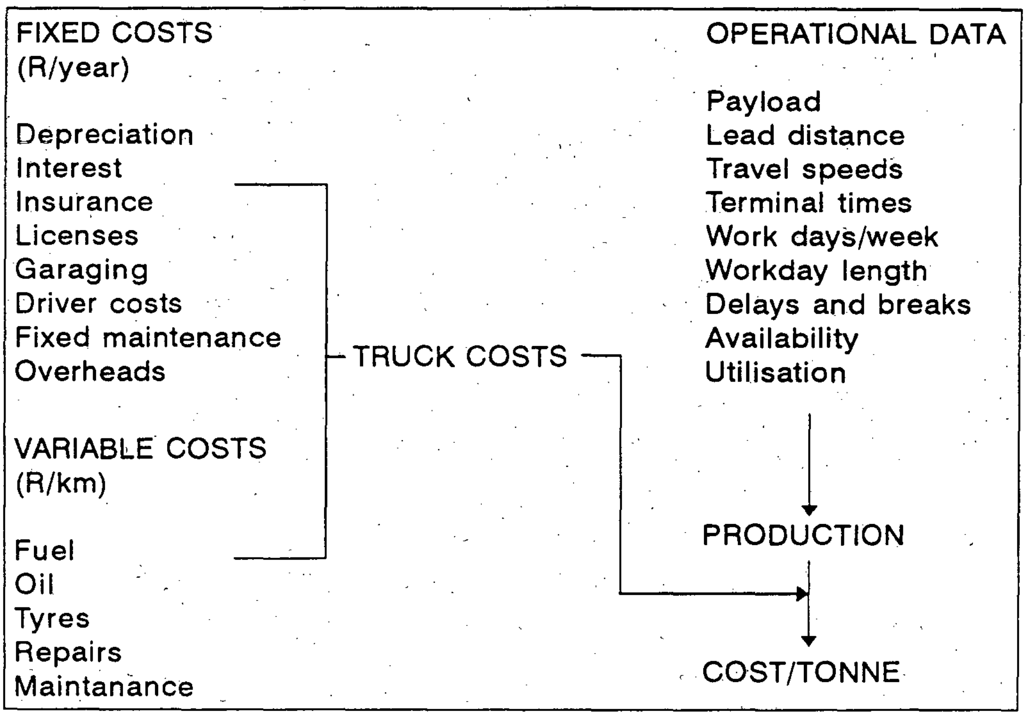
- To determine the R/tonne cost difference both between and within configurations.
- To determine the operational significance of these differences.

A secondary, and possible less theoretical objective, was to determine the cost sensitivity of the individual inputs of the programme to change.

2.2 Estimating Transport Costs

To understand the methodology used to estimate truck and ultimately transport costs, requires some understanding of truck cost calculations, and in particular the functioning of the Logtran II programme. A brief overview of the procedure is depicted and discussed below.

Figure 2.1. A breakdown of the transport costing procedure. (Adapted from Goldsack, 1988)



2.2.1 Truck cost data

Truck costs can be divided into fixed and variable costs. ***Fixed costs*** (or ownership costs) are determined on an annual basis, remain constant (fixed) and are independent of distance travelled. Depreciation, interest, insurance, licensing and overheads are traditional fixed costs. Driver costs may be regarded as a variable cost if the drivers wages can be charged to an alternate cost centre during periods when the truck is not being used. Typically though, drivers are employed to drive and costs thus remain fixed for the year. Fixed maintenance costs are not often included in calculations and refer to maintenance that must be carried out whether the vehicle is used or not.

Variable costs are only incurred when operating the vehicle and are determined on a R/km basis. As distance travelled increases, so do variable costs. Variable costs include fuel, oil, tyres and repair and maintenance. Where licence fees (road user charges) are calculated on a distance travelled basis, these are included as a variable cost.

2.2.2 **Operational data**

Operational data defines the constraints within which the truck must operate. It includes payload, lead distance, travel speeds, loading and unloading times, effective workday length and should include availability and utilisation levels.

2.2.3 **Transport costs**

The operational data determines potential production. If production is not constrained by a daily task or quota, the cost of transport is simply the cost of owning and operating the truck, for a specified period, divided by the potential production during the same period (usually a day). If production is constrained, or a set number of loads is required, transport costs are determined by dividing total costs by the constrained production. This option usually gives an indication of the number of vehicles required to achieve the target production, within the range of operational data specified.

2.2.4 **The Logtran II programme**

Logtran II is a transport costing programme written specifically for the South African forest industry. The programme assumes constrained production and is therefore driven by a required throughput in tonnes per day. The truck cost section of the programme is simple and effective. An oversight is the fact that truck-tractor and trailer capital costs cannot be treated separately to take cognisance of their different depreciation periods. A further simplification, possibly to limit the complexity of multiple drivers per shift, is to input drivers' costs as a variable cost (R/day) and then treat it as a fixed cost. This results in discrepancies when determining the effects of days worked on the per tonne cost of transport.

Operational data input is functional. The programme, however, assumes that hauliers operate at nearly 52 weeks per year, as days worked per year is derived from days worked per week. Furthermore, the programme assumes 100% mechanical availability during the effective shift and 100% utilisation of equipment during the available time. Although this is not incorrect it may be unrealistic.

Reports are numerous and detailed (see Appendix Three). Cost reports are available in R/tonne, R/km, R/trip and R/tonne/km. In each of these cases, costs are broken down into the elements comprising the costs. Costs are available in summary or detailed form and for a range of specified lead distances. Production reports give an indication of potential production, but cost the operation on the targeted production, and give an indication of the number of vehicles and trips per vehicle required over the specified range of lead distances. Fixed and variable cost reports are available, as are reports breaking down cycle times.

2.3 Economic Comparison of Configurations

2.3.1 Method

The results of the pulpwood transport survey described in Chapter One, revealed that there were fourteen variations of configurations used to longhaul pulpwood in the forest industry (refer to Table 1.2). Of these, two configurations were constructed to the old regulations and the production of five other configurations had largely been discontinued. Two configurations that had not been surveyed, but were being requested from trailer manufacturers, were also available for comparison.

To undertake a meaningful comparison and to limit the possibility of subjective data input, it was decided to limit the economic comparison to configurations for which current manufacturers' costs and design specifications were obtainable. This limited the analysis to the following configurations.

Table 2.1. Configurations subjected to economic comparison.

Configuration	Code*	Manufacturer	Surveyed
	I22-1232-3+3	A	Yes
	I22-1232-3+3	B.	Yes
	I22-1223-2+4	C	Yes
	I22-1222-2+5	D	Yes
	I22-1232-2+5	D	Yes
	SD22-12211-4+2	A	Yes
	RD22-1222-3+4	A	No
	RD22-1222-3+4	B	No

* *See key to code at bottom of Table 1.2 page 13.*

All cost data for the truck-tractor were based on that of a Mercedes Benz 2635 (the most popular turbo charged, current model surveyed). Fixed and variable costs and certain operational data were obtained from a large transport operator. Purchase price and tare mass data for truck-tractors and trailers were obtained from manufacturers, operators and trade journals. Licence fees were determined using the appropriate schedule in the Fleet Management Digest (Foresight Publications, 1995) for the KwaZulu-Natal Province. Insurance was estimated as a percentage of purchase price and overheads were expressed as a percentage of total costs.

Lead distance was taken as 120 km and required output was limited to 80 tonnes/day to force the programme to report the costs for a single vehicle. Payload was determined using a combination of the survey results verified against the legal constraints of the regulations of the Road Traffic Act. The 5% tolerance on GCM was not taken into account. The estimate of payload was a critical component in the economic comparison and its accurate estimation was complicated by the requirements of the bridge formula, no general upper GCM limit and differences in axle group spacings between similar configurations from different manufacturers. Payloads were thus the best legal estimate for each configuration. It was assumed that pulpwood density allowed maximum payloads to be achieved.

The base data remained fixed during the comparison with only the following variables changing with each configuration:

- Purchase price of trailer
- Payload
- Licence fees
- Number of tyres
- Insurance cost (expressed as a percentage of total purchase price)

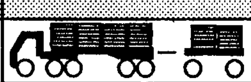
2.3.2 Results

The results of the economic comparison are tabled overleaf. They show that the semitrailer-drawbar trailer configuration (SD22-12211-3+3) had the lowest cost per tonne, followed by an interlink (I22-1232-3+3) and thirdly, a rigid-drawbar configuration (RD22-1222-3+4). The difference in R/tonne cost between the first three configurations was less than 2.2% and the difference between the first and last configuration was 17.7%. Payload and purchase price appeared to be the variables that had the greatest effect on ranking. The semitrailer-drawbar trailer had the largest payload and had the second lowest purchase price.

The third placed rigid-drawbar configuration (constructed by manufacturer B) was the first ranked seven billet configuration. Both the first and second placed configurations could carry only six billets.

Two tridem-tandem six billet interlinks (I22-1232-3+3) and two rigid-drawbars (RD22-1222-3+4) from different manufacturers were compared. The lighter (and more expensive) of the two interlinks was ranked second and the heavier ranked fourth (a 1.8% cost difference).

Table 2.2. The results of the economic comparison of the pulpwood truck configurations.

Ranking	Configuration	Manufact.	Purchase Price (Rand 000's)		Tare Weights (t)		GCM (t)	Payload (t)	Cost/Day (Rand)		R/tonne	Billets (No)
			Truck	Trailer	Truck	Trailer			Fixed	Variable		
1		A	485	225	9.60	8.19	55.7	37.90	941.7	1385.9	20.47	6
2		A	485	252	9.60	10.40	56.4	36.40	965.8	1285.1	20.61	6
3		B	485	195	11.70	7.80	56.1	36.62	912.5	1385.9	20.92	7
4		B	485	226	9.60	11.10	56.0	35.33	938.4	1285.1	20.98	6
5		A	485	230	11.25	8.00	55.9	36.65	978.8	1385.9	21.23	7
6		D	485	297	9.60	11.30	57.0	36.10	1017.8	1352.8	21.88	7
7		D	485	272	9.60	10.90	55.7	35.20	993.2	1385.9	22.53	7
8		C	485	250 [1]	9.60	13.44	56.7	33.65	978.2	1453.1	24.09 [2]	6

1 *Conservative estimate of imported purchase price*

2 *This configuration allows the rear tridem axle unit of the configuration to be piggybacked during the empty return trip which reduces tyre wear. Cost/tonne reduces to R 23.33 when tyre life is extended by 16.7%.*

A large difference in the purchase price of the two rigid-drawbar configurations (R 35 000) and a small difference in payload, resulted in a 1.5% cost difference between the configurations of the two manufacturers.

The comparison indicated that the increasingly popular 2+5 billet interlinks (ranked 6 and 7) were more economical in the tridem-tandem than the tandem-tandem configuration. The cost/tonne difference was nearly 3%.

The configuration that had the highest cost/tonne had by far the heaviest tare mass and consequently least payload.

Table 2.3 gives an indication of the annual lost revenue per truck, when assuming the R/tonne cost of the truck ranked first, to be the base.

Table 2.3. Annual lost revenue per truck.

Ranking	Tonnes hauled/Year	R/tonne Variance	Lost Revenue R/Year
1	37 862.10	-	-
2	36 363.30	0.14	5 091
3	36 596.70	0.45	16 469
4	35 294.67	0.51	18 000
5	36 630.00	0.76	27 839
6	36 063.90	1.41	50 850
7	35 164.80	2.06	72 440
8	33 616.35	3.62	121 692

Lost annual revenue per truck ranges from R 5 091 to R 121 692. When viewed in isolation these differences (for some of the configurations) may not seem significant, but when seen in the context of a large fleet, lost revenue becomes increasingly relevant.

2.3.3 Discussion

The theoretical nature of the comparison and the relatively small difference in cost/tonne between the top three ranked configurations may cause one to reconsider the assumptions made, or to question the sensitivity of the ranking to changes in the input data. If manufacturers were to reduce the purchase price or tare mass of the configurations, how would this affect the ranking? Which of the variables that determine transport costs are the most sensitive to change?

2.4 Sensitivity Analysis

To gain a better understanding of how changes to the inputs of the programme influence transport costs, and to identify those variables that have the "greatest potential impact (PI) on the bottom line, in terms of dollars [R] per unit of payload delivered", a sensitivity analysis was undertaken (Williams and Nader, 1993).

2.4.1 Method

The transport cost calculation for the fourth ranked interlink configuration (I22-1222-3+3) was randomly chosen as the base for the sensitivity analysis. The operational data used in the comparison remained unchanged. Each input variable was individually increased by 10% and the effect on R/tonne costs was noted. To verify the sensitivity of transport costs beyond the 10% increase, costs were increased by factors of 10%, or to the point where the degree of change became unrealistic. Input variables were then subjectively ranked according to their sensitivity as low, medium and highly sensitive.

2.4.2 Results

The results of the sensitivity analysis are shown in table 2.4.

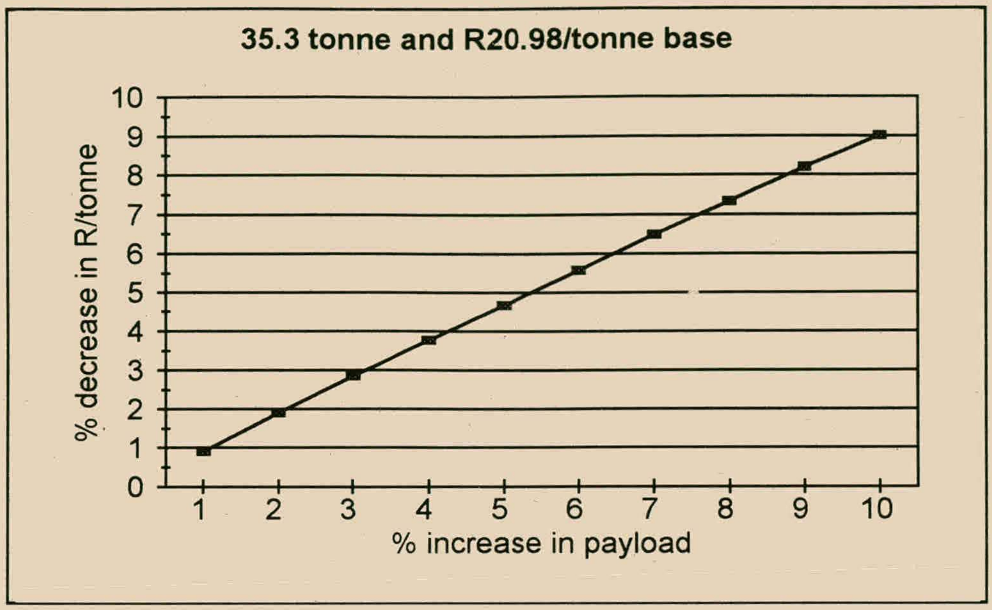
Table 2.4. Sensitivity analysis of the input variables of a pulpwood transport operation.

Input Variable	Base Figures	Change	Variance from R 20.98/tonne	Sensitivity*
Purchase price	R 711 000	+10%	+3.30%	Medium
Interest rate	18%	+10%	+1.30%	Low
Lead distance	120 km	+10%	+6.10%	High
Payload	35.3 tonnes	+10%	-9.01%	High
Tyre life	60 000 km	+10%	+1.48%	Low
Tyre cost	R1 400	+10%	+1.57%	Low
Fuel cost	R 1.493/l	+10%	+3.15%	Medium
Fuel consumption	60 l/100 km	+10%	+3.15%	Medium
Repair and maintenance	Spares 30c/km Workshop 10c/km	+10%	+1.38%	Low
Labour cost	R 100/day	+10%	+.048%	Low
Speed	55 km/h empty 33 km/h loaded	+10%	No change	Low
Terminal times	1.1 min/t load 0.5 min/t unload 25 and 20 min fixed load and unload time	+10%	No change	Low

* *Sensitivity was grouped into three categories:*	*Low*	*No change - <3%*
	Medium	*3% - <6%*
	High	*6% - 10%*

Payload showed the greatest sensitivity to change (a 9.01% reduction in R/tonne transport cost for a 10% increase in payload). For every 1% increase in payload a reduction in cost of almost 1% resulted (see Figure 2.2).

Figure 2.2. Payload sensitivity to change.



Lead distance was the next most sensitive to change (6.1%), followed by purchase price (3.3%), fuel cost (3.15%) and fuel consumption (3.15%). The remaining input variables showed a low sensitivity to change. Of interest was the nil effect of increases in travel speeds and loading and offloading times. Increases significantly beyond 10% (for the chosen base conditions) showed no reduction in the R/tonne cost of transport.

2.4.3 **Discussion**

The results clearly illustrate that payload has the greatest potential impact on transport costs. They also indicate that the cost of transport is insensitive to changes in travel speeds and terminal times, if the increase (or decrease) of these variables does not allow an extra load to be achieved (or lost) during the working day.

Changes to lead distance, tyre cost, fuel cost and interest rate are largely beyond the control of the transport manager. Changes to the remaining variables, however, are manageable and can individually or collectively, have significant impact on the cost of transport.

To determine if the base figures chosen for the sensitivity analysis (in particular the lead distance) would influence the results, a breakdown of cycle times and the elements comprising transport costs, were analysed at various lead distances. The results are shown in Figures 2.3 and 2.5.

Figure 2.3. The effect of lead distance on the breakdown of cycle times.

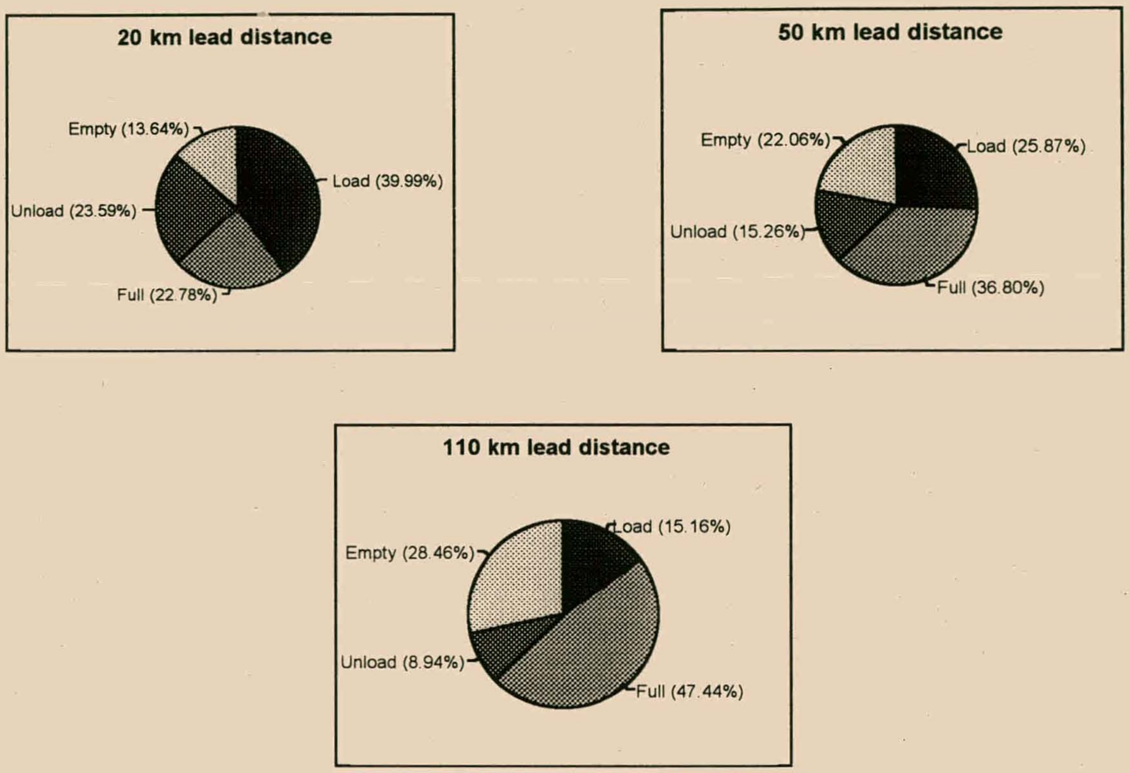
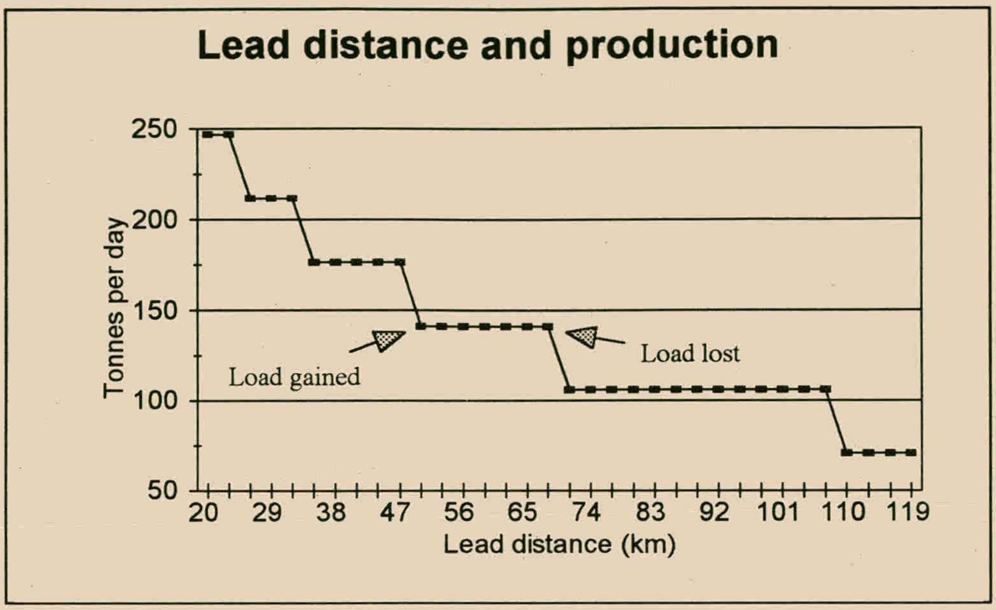


Figure 2.3 clearly illustrates that terminal times (loading and unloading) are of greater significance at shorter lead distances. One can thus infer that terminal times and speed will become increasingly sensitive to change, at shorter lead distances, as savings (in time) are quickly accumulated into additional loads. Similarly, if the lead distance chosen lies in either edge of the limit which allows an additional load to be achieved (or lost), a small increase (or decrease) can have a significant effect on the R/tonne cost, or indeed require an additional vehicle to achieve the required throughput (see Figure 2.4).

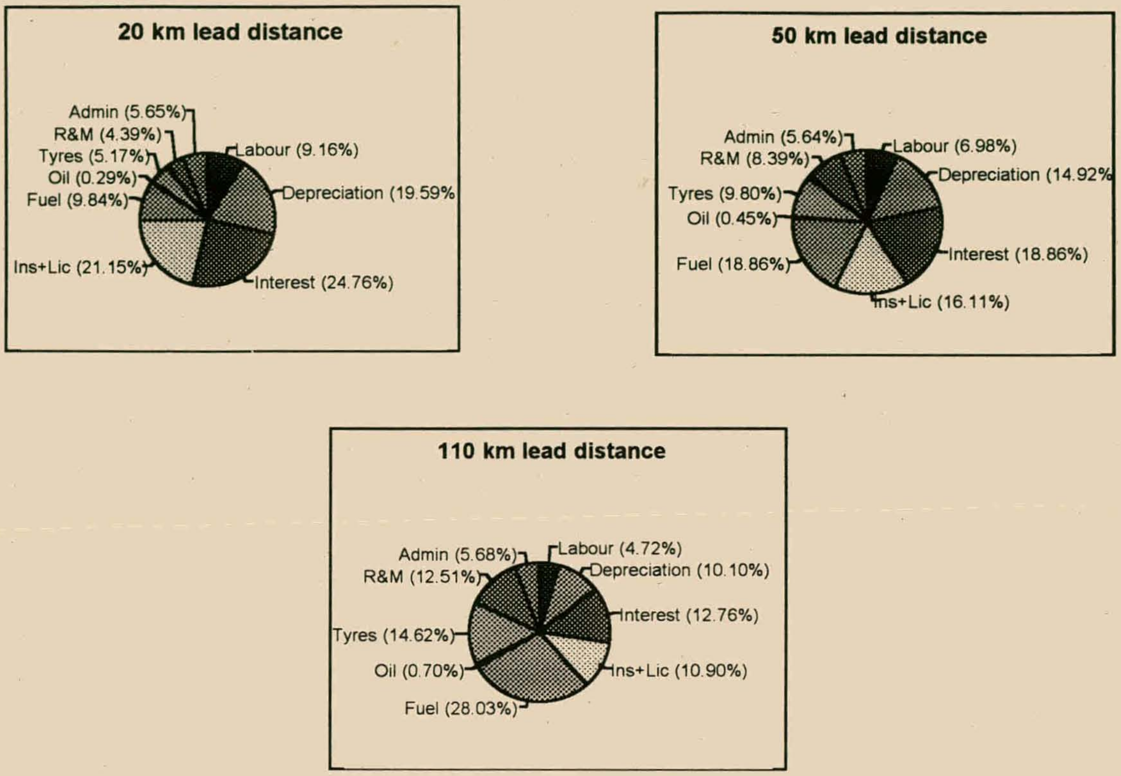
Figure 2.4. The significance of the chosen lead distance on the results of sensitivity analysis.



From Figure 2.4 it is evident that if the lead distance chosen in the sensitivity analysis was approximately 70 km, a small increase in lead distance would cause a load to be lost and transport costs to increase significantly. Similarly, if 52 km was chosen, a small reduction in lead distance would show a significant decrease in costs as an extra load is gained. When undertaking sensitivity analysis, it is therefore important to choose an appropriate base and to be aware that certain results may be specific for the chosen base.

Figure 2.5 shows the effects of lead distance on the elements that comprise transport costs. From the Figure it is clear that as lead distance increases, variable costs and in particular fuel and tyres become increasingly significant. Fuel cost, for example, increases from 9.84% of the cost at 20 km to 28.03% of the cost at 110 km. As lead distances increase, one can expect an increase in the relative sensitivity of fuel and tyres to change.

Figure 2.5. The effect of increasing lead distance on the R/tonne cost breakdown of a transport operation.



2.5 Conclusions

As transport costs account for the largest portion of the delivered cost of pulpwood, it is essential for each haulier to assess and compare the economic viability of the chosen configuration. A theoretical comparison of eight configurations revealed that:

- A semitrailer-drawbar trailer configuration had the lowest R/tonne transport cost. The configuration had the second lowest purchase price and the lowest tare mass.

- An interlink configuration and a three-axle rigid truck with a four-axle drawbar trailer had the second and third lowest transport costs respectively.

- The difference in R/tonne cost between the first and third ranked configuration was less than 2.2%. The range from first to last was 17.7%.

- A tridem-tandem 2+5 billet (2.4 m) interlink was found to be 3% more cost effective than the same configuration with a tandem-tandem axle unit setup.

- Lost annual revenue ranged from R 5 091-R 121 692 from the second to last ranked configuration.

A sensitivity analysis of the base input data used in the economic comparison revealed that:

- Increasing payload is one of the most effective ways of reducing transport costs. The relative rankings of the configurations would thus be very sensitive to a change in payload.

- Transport costs are insensitive to change in travel speeds and terminal times if the increase (or decrease) does not affect throughput (product sold).

- As lead distances increase; R/tonne costs increase, variable costs become increasingly significant and the sensitivity of transport cost variables change.

2.6 Recommendations

- Transport managers should select the most cost effective configuration for their operations and be aware of the sensitivity of, and interaction between, the variables that influence vehicle operating costs and the cost of transport. Managers should determine and focus on those cost elements that are the most sensitive to change and that can have the greatest potential impact on the cost of transport.

- Payload should be consistently maximised and should be the primary focus of strategies to reduce operating costs. To consistently maximise payload requires that the lightest economically feasible tare mass be coupled with some form of on-board weighing.

- Numerous origins and destinations of pulpwood, with varying lead distances should be encouraged, to allow accumulated time savings achieved during a shift to be converted into additional loads.

- To reduce (transport) costs managers have to increase throughput (product sold) while simultaneously reducing operating expenditure and inventory (Goldratt and Cox, 1984). If increasing utilisation and average travel speeds and reducing loading and offloading times does not increase throughput, management is focusing its attention on the wrong variables.

2.7 References

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CHAPTER THREE

The Manoeuvrability, Stability and Tractive Ability of Pulpwood Truck Configurations

3.1 Introduction

It was previously stated that longhaul pulpwood trucks operate under varying and demanding conditions. Road surface types often vary from earth and gravel forest roads, to gravel and tarred provincial roads and concrete highways, in a single trip. Although forest roads only account for a small percentage of the total trip distance (estimated to be less than 10%), the often poor condition of these roads offer significant resistances to the smooth passage of pulpwood trucks. These resistances both direct (rolling, grade and centrifugal resistance) and indirect (surface condition, horisontal alignment, site distance, etc.) increase fuel consumption and wear and tear, reduce travel speeds and productivity, and collectively increase total transport costs (Morkel, 1994).

To operate multi-articulated, long and high configurations with large payloads on forest roads, with adverse vertical and horisontal alignments and poor surface conditions, requires trucks that are manoeuvrable, stable and that have sufficient tractive ability.

The objective of this chapter is, therefore to compare the manoeuvrability, stability and tractive ability of South African pulpwood configurations so as to discover which are most suited to the prevailing operating conditions. Manoeuvrability was determined by measuring low-speed offtracking, swept path and reversibility of the three configuration types, in field trials. Determining the stability of the configurations (in terms of Static Roll Threshold, Dynamic Load Transfer Ratio, High-Speed Transient Offtracking and Yaw Damping Ratio) proved more difficult and expensive. Differences between configurations were thus assessed based on limited, simulated research findings. The differences in tractive ability between the three configuration types were also theoretically determined and briefly discussed.

3.2 The Manoeuvrability of Pulpwood Configurations

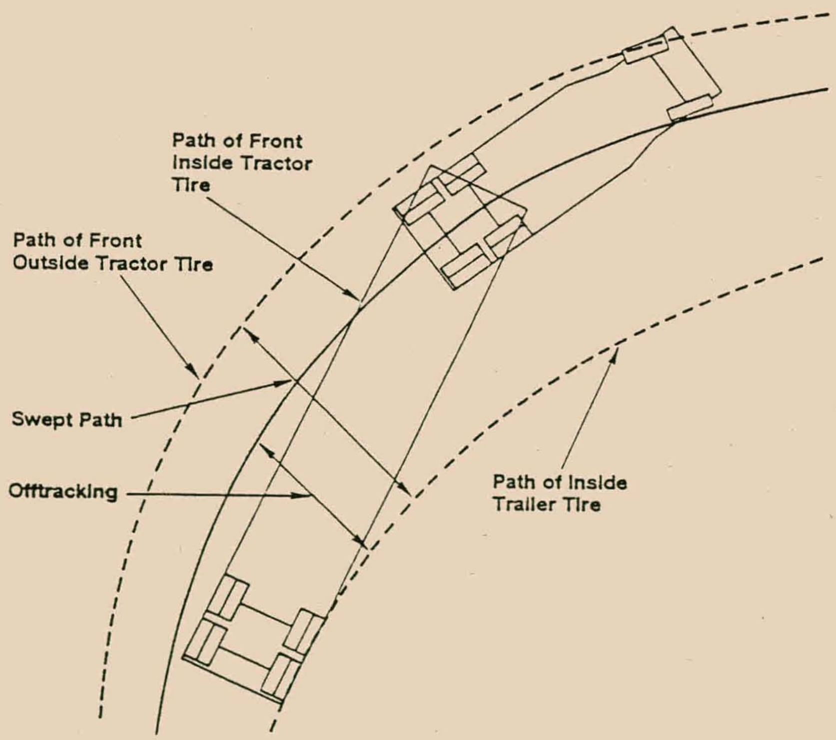
3.2.1 Defining and measuring manoeuvrability

The manoevrability of vehicles is usually determined by measuring low-speed offtracking and swept path. A third criteria, reversibility, has been included in this thesis.

3.2.1.1 Low-speed offtracking

The manoeuvrability of a vehicle is most commonly assessed by measuring low-speed offtracking (from now on referred to simply as offtracking). Offtracking is the phenomenon which occurs when the path of each rearward tyre of a turning vehicle does not coincide with that of the corresponding forward tyre, with the result that the vehicle cuts the corner, or is unable to stay within the proper lane. Offtracking is measured as the distance (in metres) between the outer edge of the path of the front inside tractor tyre, and the outer edge of the path of the rearmost inside trailer tyre (see Figure 3.1).

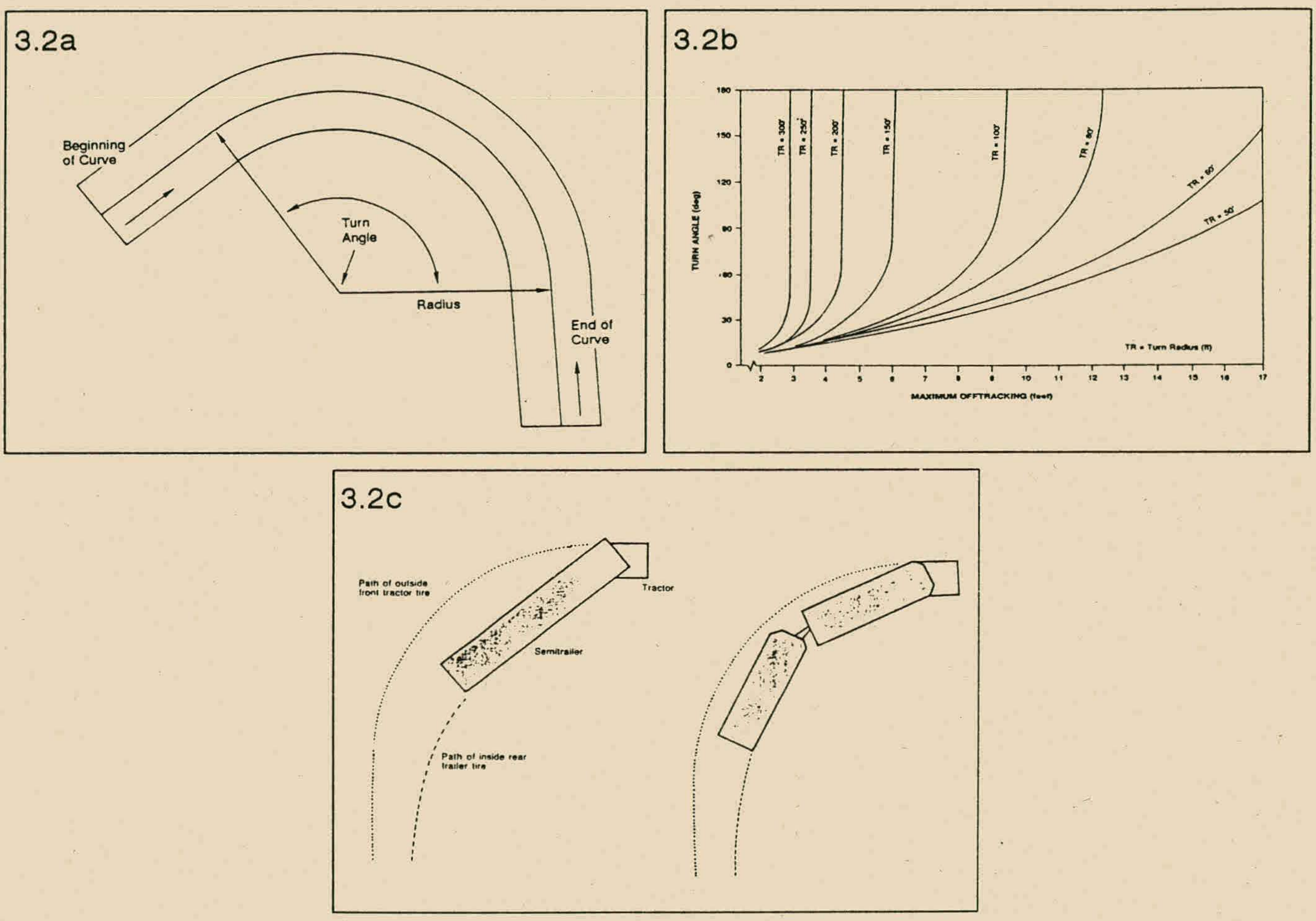
Figure 3.1. Measuring offtracking and swept path.



The extent of offtracking is a function of both the curve geometry (curve radius and central curve angle - see Figure 3.2a) and the dimensions of the vehicle. Offtracking increases with:

- Shorter curve radii (see Figure 3.2b).
- Longer central curve angle (see Figure 3.2b).
- Longer vehicle wheel bases (see Figure 3.2c).
- Fewer vehicle articulation points (see Figure 3.2c).

Figure 3.2. Curve geometry and factors influencing offtracking. (TRB, 1989 and 1990)



Offtracking can be measured in field trials, by using scale models (such as the Drafting Vehicle Simulator described by Kramer, 1987), mathematical formulas and computer programmes (such as the UMTRI/Caltrans and OFFTRACK programmes) described in Transportation Research Board (TRB), 1989 and by Erkert *et al*, 1990. The computer programmes can provide precise measurements of offtracking but may overstate offtracking in situations in which the vehicle pulls out of a turn before maximum offtracking occurs (TRB, 1989). Offtracking simulations using the OFFTRACK programme provided results within 0.15 m of both scale model simulations and field measurements, and was deemed to predict offtracking with reasonable accuracy for use as a road design tool.

3.2.1.2 Swept path

A measurement of manoeuvrability closely associated with offtracking is swept path (or swept width). Swept path refers to the width of the roadway the vehicle occupies when negotiating a curve (the amount of offtracking plus the width of the vehicle - see Figure 3.1). Swept path is measured as the distance (in metres) between the path of the outer edge of the inside rear trailer tyre, and the outer edge of the front outside tractor tyre. Swept path gives an indication of the minimum road width required for a specified configuration taking a specified curve. The OFFTRACK simulation programme overestimated swept paths for certain multi-articulated configurations.

3.2.1.3 Reversibility

The third criteria used to measure the manoeuvrability of pulpwood configurations was reversibility. It was defined as the ease with which a configuration was able to reverse through a corridor of specified length and width. This unusual criteria was included, as the operating conditions on plantations (such as blocked roads and confined depot space), often necessitate that trucks reverse over short distances.

3.2.2 **Manoeuvrability field trials**

3.2.2.1 Overview

The longhaul pulpwood survey revealed that three configuration types and fourteen variations within the three types were used to transport pulpwood (see Table 1.2). Due to the dominance of the interlink configuration, two interlinks (an old and an emerging variation) were assessed, along with a rigid-drawbar and semitrailer-drawbar trailer configuration. The configurations tested and relevant data for each is tabled below.

Table 3.1. Configurations tested for manoeuvrability.

Configuration	Length (m)	Front axle width (m)	Loaded	Articulation points
I22-1232-2+5	22.00	2.34	No	2
I22-1222-3+3	21.56	2.34	No	2
RD22-1222-2+4	21.60	2.34	No	2
SD22-12211-4+2	21.60	2.34	Yes	3

It was decided to use field trials as the means of measuring offtracking. This approach was adopted for the following reasons:

- To obtain real (as apposed to simulated) data.
- The OFFTRACK programme was not metricated and did not cater for South African configuration types.
- Other simulation programmes proved difficult to obtain.

No methodology for the reversibility test could be found. Discussions with the Road Freight Association, driver training schools, Gerotek and the University of Pretoria revealed that no such tests had been conducted in South Africa. The methodology used was therefore developed by the author.

3.2.2.2 Offtracking and swept path field trials

3.2.2.2.1 *Method*

Two trials were conducted. The first determined the offtracking and swept paths for the three configuration types on a 15 m radius, 90 degree central angle curve. The second determined the maximum offtracking and maximum swept paths on the tightest constant radius curve that the configurations could take (without causing wheel drag or with the constraint that the trailer wheels remained turning). Both trials were conducted on a large, flat gravel surfaced depot. Trucks for the trials were provided by two independent transport contractors.

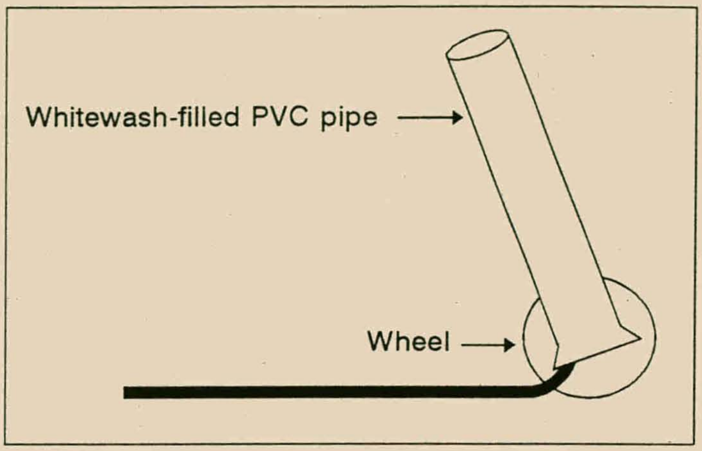
The first trial required that a 15 m radius, 90 degree central angle curve be marked on the depot surface with a solid line of whitewash powder. The beginning and end points of the curve were marked with red powder paint, and the approach to and departure from the curve (tangents) were marked with a dotted line of whitewash powder.

Drivers were instructed to park the trucks parallel to and touching the dotted line marking the approach to the curve, with the inside (in this case right) front wheel at the marked beginning of the curve. (Prior to the trial being conducted, numerous dimension measurements of the trucks were recorded as input data for simulation programmes, should it have been necessary). The drivers were then instructed to drive the configuration through the curve with the outer edge of the inside front wheel just touching the line. An assistant walked next to the wheel to give feedback to the driver to ensure that the wheel constantly touched the line. As the truck was taking the curve the position of the outer edge of the inside rear trailer tyre was marked on the ground using specially designed applicators (whitewash-filled 45 mm PVC tubing with constricted outlet and side-mounted wheel - see Figure 3.3).

On reaching the end of the curve the drivers were instructed to follow the dotted tangent line so that the whole configuration passed through the curve. Four different colours were used to mark the offtracking lines for the four configurations.

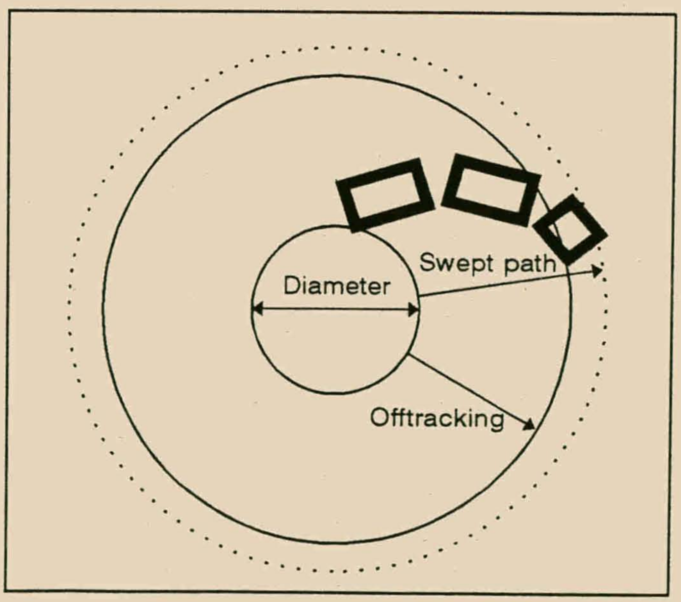
Offtracking distance was measured as the perpendicular distance from the point of widest offtracking to the curve line. Swept path was calculated by adding the offtracking distance to the front axle width (outer edge of tyre to outer edge of tyre). The methodology followed was similar to that used by the United States Department of Agriculture (USDA) Forest Service and the California Department of Transport (Caltrans) described in Erkert *et al*, 1990.

Figure 3.3. Whitewash applicator used in the trials.



The trial to measure maximum possible offtracking and swept path required no markings. Drivers were instructed to turn the truck in the tightest constant radius curve while ensuring that all wheels continued to turn. Once the configuration had achieved a constant radius curve (circle) the path of the inside front and inside rear tyres was marked using the applicators. Maximum offtracking was measured at the widest perpendicular distance between the path of the rear inside and front inside tyres. Maximum swept path was determined by adding this distance to the front axle width. The diameter of the circle made by the rear inside tyre was also measured. Figure 3.4 illustrates the trial procedure followed.

Figure 3.4. An illustration of the maximum offtracking and swept path trial procedure.



3.2.2.2.2 *Results and discussion*

The results of both trials are shown in Table 3.2.

Table 3.2. The results of the offtracking and swept path manoeuvrability trials.

Configuration	15 m radius, 90 deg trial		Maximum offtracking/swept path trial		
	Offtracking (m)	Swept path (m)	Offtracking (m)	Swept path (m)	Inner radius (m)
I22-1232-2+5	4.20	6.54	9.14	11.48	3.96
I22-1222-3+3	3.90	6.24	7.58	9.92	3.93
RD22-1222-2+4	3.17	5.51	7.27	9.61	2.68
SD22-12211-4+2	3.00	5.31	7.16	9.50	2.42

The configuration data in Table 3.1 shows that the 2+5 billet interlink was the only configuration that was 22 m long. As a new trailer it had been designed and constructed to the new dimension regulations of the Road Traffic Act. The three remaining configurations were all approximately 21.6 m in length, which indicates that they were originally constructed to the old 20 m regulations and later converted to the new regulations. The results in Table 3.2 should, therefore, be interpreted taking cognisance of this 40 cm length difference. The results of the last three configurations, which reflect each of the configuration types, are thus more comparable and meaningful. The results of the maximum offtracking and swept path trial should also be viewed with a certain degree of caution, as configurations often did not make perfect circles, which necessitated some estimation.

The semitrailer-drawbar trailer configuration showed the greatest manoeuvrability in terms of the offtracking and swept path criteria. It also had the smallest inner radius. The rigid-drawbar configuration was the next most manoeuvrable with 0.17 m more offtracking and swept path. The old interlink was next most manoeuvrable, followed by the new interlink. There was 0.9 m and 1.2 m difference in offtracking and swept path between the semitrailer-drawbar trailer and the old and new interlinks, respectively.

Of particular interest is the relative and maximum swept paths of the various configurations. Main and secondary South African forest roads typically range in width from 6-9 m with an unspecified amount of inner widening on corners, to account for offtracking. The results show that all four configurations will find it difficult to remain within their travel lane when taking corners of even moderate curve radii. The results further indicate that the configurations can take corners with small inner radii (2.42-3.96 m), provided that significant allowance has been made for swept path (9.5-11.48 m). It should be noted that curves of such tight geometry would not be encountered on a well designed forest road network, as they are too dangerous and would severely restrict travel speeds and thus transport productivity. The results may prove of more use when designing depots, landings or truck turning circles.

3.2.2.3 Reversibility trials

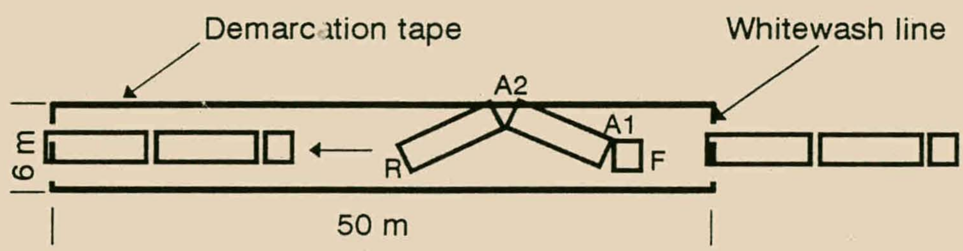
3.2.2.3.1 *Method*

As mentioned in section 3.2.2.1, no reference to a reversibility test could be found. Following discussions with numerous institutions and on the advice of Professor A van Laar (personal communication, 1995) the following methodology was chosen.

Two competent drivers per configuration type would make two attempts at reversing the truck through a corridor 50 m long and 6 m wide. The length was chosen at random and represents approximately 2.3 truck lengths. The width of 6 m was chosen to reflect the width of a typical forest road. The sides of the corridor were marked with demarcation tape, suspended between metal posts and the start and end of the corridor were marked with whitewash (see Figure 3.5 for layout of trial).

During each attempt, the time to complete the distance, the number of times the demarcation tape was crossed, the point of crossing on the configuration and the number of direction changes were noted. One assistant measured the time, direction changes and recorded the data, while a further two assistants (one on each side of the corridor) monitored the number of crossings and the points of crossing.

Figure 3.5. Reversibility trial layout and procedure.



3.2.2.3.2 *Results and discussion*

The results of the reversibility trials are tabled overleaf.

The shortcomings of the adopted methodology (in terms of drivers) soon became apparent as the trial progressed:

- The skill (or lack thereof) of the drivers was being tested more than the ability of the configuration to reverse. It was initially felt that two competent drivers, each undertaking the test twice, would negate the influence of the driver on the test results. It soon became evident that even normally good drivers were not competent at reversing, as they did it infrequently and the trucks were essentially not designed to reverse.

Table 3.3 Results of the reversibility trials.

Configuration	Order of trial	Driver	Time (min)	Crossings	Point of crossing				Direction changes
					Front	Artic 1	Artic 2	Rear	
I22-1232-2+5	5	Anson	2.36	-	-	-	-	-	1
		Anson	3.29	-	-	-	-	-	1
	6	Shaun	5.43	6	1	-	5	-	4
		Shaun	4.36	1	-	-	1	-	5
I22-1222-3+3	3	Shaun	5.02	13	6	4	1	2	3
		Shaun	2.00	4	2	1	1	-	1
	4	Anson	9.45	1	1	-	-	-	5
		Anson	5.27	-	-	-	-	-	4
	8	Shezi	0.49	-	-	-	-	-	-
		Shezi	0.32	-	-	-	-	-	-
RD22-1222-2+4	1	Shezi	1.13	-	-	-	-	-	-
		Shezi	1.01	-	-	-	-	-	-
	2	Shaun	4.09	3	2	-	-	1	3
		Shaun	Abandoned	n/a	n/a	n/a	n/a	n/a	n/a
SD22-12211-4+2	7	Shezi	Abandoned	n/a	n/a	n/a	n/a	n/a	n/a

- The predominance of the interlink configuration made it difficult to find competent drivers for the other configuration types. Drivers were capable of driving the configurations forward but not in reverse.

The variability of the results of the trial clearly illustrate the influence of the drivers. Analysing the results for the two interlink configurations (and excluding the results of Shezi) showed that times ranged from 2 minutes with one direction change to 9 minutes 42 seconds with one crossing and five direction changes. Some runs recorded up to thirteen crossings.

It soon became obvious that the most meaningful results would be obtained if a single competent driver were to undertake the test with each configuration type. Initial results indicated that Shezi was the most competent driver. As a transport supervisor, experienced in driving all three configuration types, he was selected as the driver. The results of Shezi were thus taken as representative of the ability of each configuration type to reverse.

These showed that both the interlink and rigid-drawbar trailer configurations could easily be reversed by competent drivers. The best times for the two configuration types were 32 and 61 seconds, respectively. It was not possible for the semitrailer-drawbar trailer to be reversed. The main reason offered for the inability of this configuration to reverse, was the number of articulation points (fifth wheel, trailer hitch and trailer turntable). As a result of the dual articulation on the drawbar trailer, the direction of the trailer could not be controlled during reversing. It should be noted that due to the limited availability of semitrailer-drawbar trailer configurations, and time constraints, this was the only configuration that was tested while loaded. Personal communication with the driver and numerous operators have confirmed that it is not possible to reverse this configuration whether laden or empty.

3.2.2.4 Conclusions

The results of the manoeuvrability field trials lead to the following conclusions:

- The semitrailer-drawbar trailer is the most manoeuvrable configuration (in terms of offtracking and swept path), closely followed by the rigid-drawbar trailer configuration and lastly the interlink configurations.

- The interlink and rigid-drawbar configurations could be reversed with ease by competent drivers.

- It was not possible to reverse the semitrailer-drawbar trailer configuration.

3.3 The Stability of Pulpwood Configurations

Research on the stability of truck configurations in South Africa has been severely neglected. The extent of this neglect is best illustrated by recent amendments to the dimension regulations of the Road Traffic Act. Changes to the regulations increased length, height and width dimensions by 2 m, 0.2 m and 0.1 m respectively. At no stage were the impacts of these changes on the stability of truck configurations taken into account (pers comms Sutherland, 1995).

A telephone survey of the Roads and Transport Technology Division of the CSIR (Transportek), the Department of Transport, the Directorate of Traffic Safety, the Road Freight Association, the South African Bureau of Standards and the transport engineering departments of a number of universities, revealed little understanding of vehicle stability and the criteria for testing stability.

Discussions with Gerotek (a vehicle testing facility), the Laboratory for Advanced Engineering (LAE) at the University of Pretoria and the trailer manufacturer Henred Fruehauf, identified a centre of expertise for stability testing in the country, and revealed that the first stability tests on a commercial interlink configuration were conducted in late November, 1994. The stability tests were initiated by the trailer manufacturer to quantify their concerns on the effect of the new dimension regulations on the stability of their trailers. The tests were first simulated by the LAE and later verified in field trials at Gerotek (pers comms Naude, Lehmann and Steyn, 1995).

3.3.1 Defining and measuring stability

The stability of vehicles is measured in terms of static and dynamic parameters. Static stability (or roll stability) is determined by the Static Roll Threshold. Dynamic (or lateral) stability is primarily determined by the Dynamic Load Transfer Ratio, High-Speed Transient Offtracking and the Yaw Damping Ratio.

Measuring these parameters is complex and costly. As road or field tests to measure stability are unsafe and laboratory tests are limited, most stability measures are determined by computer simulation (Das *et al*, 1993).

3.3.1.1 Static stability parameters

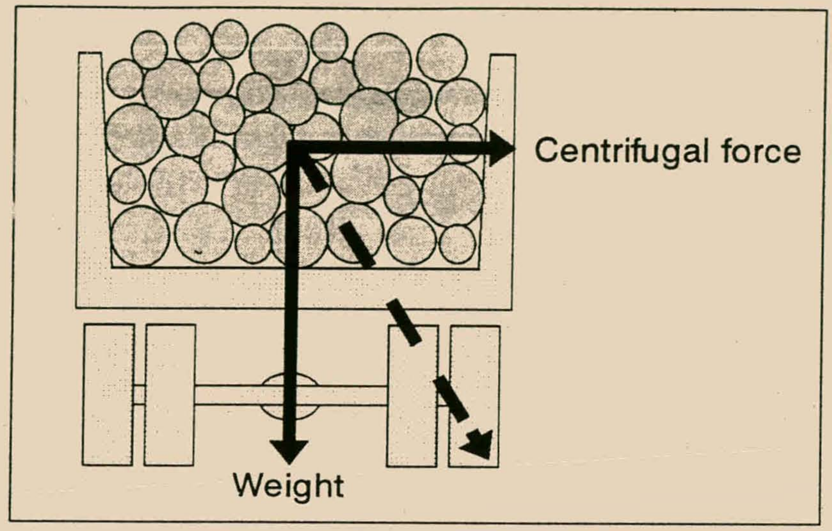
3.3.1.1.1 *Static Roll Threshold*

The Static Roll Threshold (SRT) is the level of lateral acceleration that a truck can achieve during turning without rolling over. It is measured in units of g's with the minimum target value for a truck being 0.35 g (White, 1994). The Roads and Transportation Association of Canada indicate that, in general, loaded vehicles have a SRT in the range of 0.25-0.40 g and recommend a target level of 0.4 g or better (Amlin, 1992). Higher values imply better resistance to rollover.

Rollover is a particularly severe form of instability and is usually caused by excessive speeds of vehicles operating on curved paths. It results when the overturning moment due to centrifugal force, exceeds the weight-related restoring moment (see Figure 3.6).

SRT is very sensitive to the ratio of the overall width to the outside of the tyres on an axle, to the height of the centre of gravity of the payload. As this ratio increases, either by increasing width or by decreasing the height of the centre of gravity, SRT increases. (TRB, 1990 and Amlin, 1991).

Figure 3.6. Rollover occurs when centrifugal force induced overturning moment exceeds weight-related restoring moment.



3.3.1.2 Dynamic stability parameters

3.3.1.2.1 *Dynamic Load Transfer Ratio*

The Dynamic Load Transfer Ratio (DLTR) is an expression of dynamic roll stability. It is defined as the sum of all the vertical tyre forces along the left hand side of the vehicle (except the steer axle), divided by the corresponding sum for the right hand side. When travelling on a straight, level road, a vehicle will have a DLTR of 0.0. At the limit when all wheels (bar those of the steer axle) on one side of the vehicle lift, the DLTR is 1.0. The target value for DLTR is ≤ 0.6. (White, 1994)

3.3.1.2.2 *High-Speed Transient Offtracking*

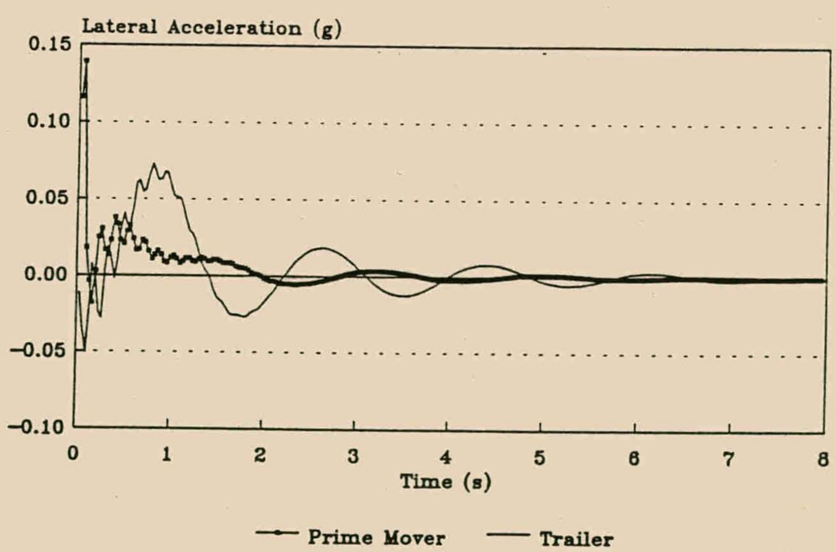
High-Speed Transient Offtracking (HSTO) is the opposite of low-speed offtracking (discussed in section 3.2.2.1). It occurs during high speed cornering (or rapid path change), when the wheels of the rearmost axle track outside the path of the wheels of the front most axles. HSTO is measured in metres and is expressed as the maximum distance between the paths of the outside tyres and on the front and rear axles (TRB, 1986 and 1990). A target value for HSTO is ≤ 0.6 m (White, 1994). Under high speed operation, high-speed offtracking:

- Increases with additional articulation points.
- Decreases with longer effective wheelbase.
- Decreases with lighter axle loads.

3.3.1.2.3 *Yaw Damping Ratio*

Yaw Damping Ratio (YDR) is a measure of how rapidly yawing motions (yaw is rotation around a vertical centreline and yawing is changing direction) are damped out. It is determined by subjecting the vehicle to a pulse steer input at highway speed (usually 100 km/h). YDR is calculated from the ratio of amplitudes of successive oscillations. The typical vehicle response to this steer input is illustrated in Figure 3.7. The rearmost trailer (in the Figure) exhibits the classical damped oscillation, with successive peaks decaying exponentially. (While lateral acceleration has been used in Figure 3.7, yaw rate or roll angle could also have been considered). The target value for YDR is ≥ 0.05. (White, 1994)

Figure 3.7. Characteristic decaying (damped) response to pulse steer input used to determine Yaw Damping Ratio. (White, 1994)



3.3.2 Research findings

There has been no research undertaken to detect stability differences between the three configuration types, used to transport pulpwood (or general freight) in South Africa. As mentioned earlier the first stability tests on a commercial trailer were only conducted during the latter half of 1994. The prohibitive costs of stability tests (R 60 000-R 70 000 per vehicle) suggests that few such tests will be conducted in the future. Furthermore, the multitude of truck variables that may effect stability (vehicle dimensions, axle widths, suspension type, spring stiffness, tyre stiffness, bunk attachment, product and payload height, etc), make research results specific for each vehicle and thus difficult to extrapolate and compare.

The only comparative research on the stability of the three configuration types was the "cursory initial assessment of the stability performance of typical New Zealand logging vehicles" conducted by White of Industrial Research Limited, New Zealand (White, 1994). According to White (pers comms, 1995), "Apart from Static Roll Threshold, the other parameters to measure stability are best tackled using computer simulation".

3.3.2.1 Static stability parameters

3.3.2.1.1 *Static Roll Threshold*

The differences in Static Roll Threshold for the three configuration types tested by White (a 6-axle semitrailer, an 8-axle tridem-tandem interlink and a 3-axle rigid truck with 4-axle drawbar trailer) were 0.34 g, 0.33 g and 0.31 g, respectively. All values fell below the target value of ≥ 0.35 g.

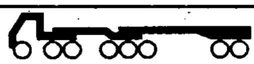
White (1994) found that stability could be improved considerably if the load centre of gravity was reduced and axle widths increased. He suggested that trailers be designed to accommodate five billets as apposed to four, to lower the height of the load centre of gravity (by up to 20%). He also found that increasing the axle width by 0.1 m would increase stability by at least 10%.

Amlin (1991) found that rollover stability of logging vehicles could be improved by increasing the track width of the axles and reducing the bunk lash (the latter recommendation is not applicable to South African pulpwood trucks). He found increasing axle width from 2.4 m to 2.6 m improved the SRT from 0.282 g to 0.315 g (a 12% improvement).

3.3.2.2 Dynamic stability parameters

The only reference to dynamic stability parameters of relevance to local configurations is that of White. The results of all three parameters are collectively shown in Table 3.4.

Table 3.4. A comparison of dynamic stability parameters for typical New Zealand logging trucks. (White, 1994)

Configuration	DLTR	HSTO (m)	YDR
	**0.63**	0.39	>0.30
	0.53	0.41	>0.30
	**0.67**	0.35	0.28
Target value	≤ 0.60	≤ 0.60	≥ 0.05

Values in bold fall outside of the target value.

With the exception of the Dynamic Load Transfer Ratio of the semitrailer and rigid-drawbar trailer configurations, the results for the stability parameters fall within acceptable levels.

The results of the work of White and Amlin reflect dimension and design criteria unique to the countries where the research was conducted (New Zealand and Canada). Weights and sizes of trucks in these countries differ from those in South Africa, allowing for only generalisations to be made, and making direct comparisons of research findings difficult (particularly those of White).

3.3.3 Conclusions

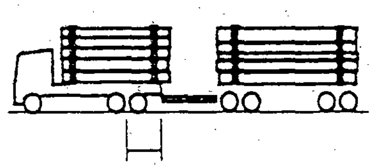
The results of international stability research findings may appear to be of little practical merit. Extensive research has been conducted on configurations uncommon in South Africa, or not constructed to local weight and dimension regulations. Results are therefore, not directly comparable and at best offer only unsubstantiated speculation as to which of the local configuration types are more stable.

The results, however, do allow us to make the following meaningful conclusions:

- Substantial gains in stability are possible if the load centre of gravity is lowered. Making use of configurations with seven 2.4 m billets, as apposed to six (while keeping payloads constant), the use of low profile tyres and small rims, and utilising the "dead space" below the chassis height between the axles of trucks, will all assist in lowering the height of load centre of gravity (CG), making configurations more stable. It should be noted that every measure of stability discussed improves markedly as load centre of gravity height is reduced.

- Increasing the axle track width will make configurations significantly more stable.

- The longer the hitch overhang (longitudinal distance from the hitch forward to the rear axle - see insert) on rigid-drawbar configurations, the less the dynamic stability. A large hitch overhang acts to amplify the motion of the truck rear, causing larger sideways displacements of the drawbar eye. Since lateral movement of the drawbar eye steers the trailer, increased trailer yawing results (White, 1994).



- Careful attention must be paid to the selection of tyres, suspensions and method of bunk attachment as they can make large differences to the stability performance of vehicles. It should, in particular, be noted that the use of single tyres on trailers has the potential to reduce effective track width and thus stability of pulpwood configurations. Mc Cormack (pers comms, 1995) has confirmed that the increasing trend to fit single tyres to trailers (as apposed to dual tyres) has resulted in a marked decline in configuration stability.

White (1994) concluded that, "Present [New Zealand] logging truck stability is at the low end of the spectrum". Local concerns by trailer manufacturers and some operators, may lead one to assume that the situation is no better in South Africa.

3.4 The Tractive Ability of Pulpwood Configurations

As with vehicle stability, no research to determine differences between the tractive ability of the three configuration types has been undertaken in South Africa. In contrast, Wild (1990), has conducted extensive research on the tractive abilities of various Canadian logging trucks and together with Amlin (1992) and Williams (1995), has assessed various technologies to improve the tractive abilities of these configurations. Other than the latter work, this research has little local significance, as South African configurations differ greatly.

3.4.1 Defining and measuring tractive ability

Kellogg (1993) simply defines traction as the driving force developed by a wheel as it moves upon a surface. The weight the wheel carries and the ground surface condition determine whether enough traction exists (in which case the vehicle moves forward), or if there is insufficient traction (causing the wheel to slip). The degree of traction between the tyre and the ground surface is called the coefficient of traction. The coefficient for rubber tyres ranges from 0.9 on concrete to 0.35 on a loose gravel road.

Tractive ability can be measured in field trials using the drawbar pull test. This test is designed to simulate, on a level road, the forces experienced by a vehicle when climbing a grade at constant speed. The tractive ability determined by the drawbar pull test (measured in kN) is thus typically converted into equivalent gradability and expressed in percent grade (Wild, 1990). Tractive ability can also be determined using computer models. Wild (1990) found that the interaction between the road and the tyre was not easily modelled on computer and favoured the use of field trials. Amlin (1992) extensively used computer modelling in his research and documented the development of a traction/gradability algorithm.

3.4.2 Research findings

The only reference of interest identified was that of Williams (1995). He found that the main disadvantage of the interlink (B-train) configuration was its lower tractive ability when compared with conventional eastern Canadian semitrailer configurations. Although the interlink had a higher GCM, the semitrailer configuration transferred more weight to the drive axles, improving traction. Williams calculated a gradability of 6.7% for the tri-axle semitrailer and 5.6% for the interlink (on snow packed roads). In order to increase the gradability of the interlink to the same level as that of the semitrailer, an additional 3 500 kg would have to be transferred from the centre tridem axle unit to the drive axles, or that traction be improved by 18-20%. To achieve the same tractive ability of the conventional semitrailers, Williams suggested that interlinks be fitted with traction-assist devices.

Numerous researchers have commented on methods and devices to improve the tractive ability of log truck configurations. Traction-assist devices can be divided into two groups: those adding weight to the drive axles, including;

Two setting king pins Optional sliding king pins or dual king pins which allow a highway legal king pin setting, as well as a forest road setting that maximises drive axle weight.

Sliding fifth wheel Adjustable fifth wheels that allow the fifth wheel to be positioned in such a way to transfer additional weight to the drive axles.

Lift axles	Lifting trailer lift axles off the ground transfers weight to the drive axles.
Tridem-axle traction	Significant improvements in gradability can be realised by tridem axle unit truck-tractors employing a liftable non-driven axle. The tridem axle unit has a greater legal payload, most of which is transferred onto the two drive axles when lifting the non-driven third axle during travel on forest roads (Amlin, 1992).

and those improving the traction coefficient between the tyres and the road, such as;

Central tyre inflation	Central Tyre Inflation (CTI) systems allow the truck driver to modify the vehicles tyre pressure according to the load, road conditions and travel speed. At lower pressures tyres have a longer footprint which significantly improves traction.
Locking differentials	Locking differentials enable the vehicle to take advantage of the best traction available under the drive wheels by transferring available torque to wheels that can use it (Williams, 1995).

Following a comparative analysis of various traction-assist devices, Williams (1995) recommended the use of CTI to improve the tractive ability of interlink configurations.

3.4.3 **Discussion**

Limited research findings make it difficult to differentiate between the tractive ability of the three pulpwood configuration types. The work of Williams (1995), described in detail in the preceding section, is largely of academic interest as the permissable mass load for tandem (drive) axle units in South Africa is limited to 16 400 kg regardless of the configuration type (Regulation 365 of the Road Traffic Act). The additional weight transferred to the drive axles of an interlink configuration and improved traction may thus only prove advantageous when travelling on private forest roads (exempt of axle mass load limitations) or when travelling empty.

3.4.4 Conclusions

No local and little relevant international research on the tractive ability of the three pulpwood configuration types used in South Africa limits us to the following conclusions:

- It is currently not possible to differentiate between the tractive ability of the three configuration types.

- Increasing the tractive ability of local configurations is limited to the use of traction-assist devices that improve the traction coefficient. Central Tyre Inflation systems and locking differentials are options to consider.

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CHAPTER FOUR

Product and Configuration Considerations

4.1 Introduction

Transport can be simply defined as the ***movement*** of a ***product*** over a ***distance***. Effective transport, therefore, requires a comprehensive understanding of the mode of transport (movement), the product and the route (distance and terrain) from its origin to destination.

The route to be taken largely determines the mode of transport (road, rail, water or air) and the product the most effective carrier. The dimensions and density of the product are the most important determinants of the most effective carrier.

Pulpwood varies considerably in both dimension and density. Such variation of the product, coupled with the cost of the operation, negates a single, simple solution to the choice of most effective carrier (in this case a truck configuration).

The objective of this chapter is, therefore, to determine how pulpwood length and density influence the selection of the most appropriate pulpwood truck configuration.

4.2 Product Length

4.2.1 Overview

The results of the survey described in Chapter One revealed that five different product lengths were transported (refer to sections 1.3.2.4 and 1.3.3.4). Eighty point six percent of pulpwood was transported in 2.4 m lengths, 7.87% in 3.0 m lengths, 5.27% in 5.5-6.0 m lengths and the remainder in 7.2 m lengths.

Further investigation showed that all pulpwood mills accept 2.4 m lengths. One pulpmill accepts 2.4 m, 3.0 m and 6.0 m lengths, another 2.4 m and 5.5 m lengths and a third 2.4 m and 7.2 m lengths. All species were transported in 2.4 m lengths. The 3.0 m, 5.5 m and 6.0 m lengths were only hardwood species and the 7.2 m lengths only softwood species.

As 2.4 m lengths predominate, most configurations have been designed to accommodate this length. The shift towards longer lengths, initiated to reduce harvesting and handling costs, has necessitated that most new configurations have the ability to carry 2.4 m, 3.0 m or 6.0 m lengths. To determine if such product versatility is warranted and if certain product lengths are more suited to certain configurations, a study of the influence of product length on the choice of configuration was conducted.

4.2.2 **Pulpwood length and configuration considerations**

4.2.2.1 Method

A closer analysis of all the pulpwood configurations surveyed revealed that there were only four decklength options available. The options are tabled below.

Table 4.1. **The four possible decklength options identified.**

Configuration	Decklength (m)		
	Unit 1	Unit 2	Total
Semitrailer-drawbar trailer	11.0	5.5	16.5
Rigid-drawbar trailer	7.5	10.5	18.0
Interlink (9.2-9.2)	9.2	9.2	18.4
Interlink (6-12.5)	6.0	12.5	18.5

Decklength specifications were obtained from current design drawings. Minor and insignificant variations in the length of different units were noted between the various manufacturers.

4.2.2.2 Results

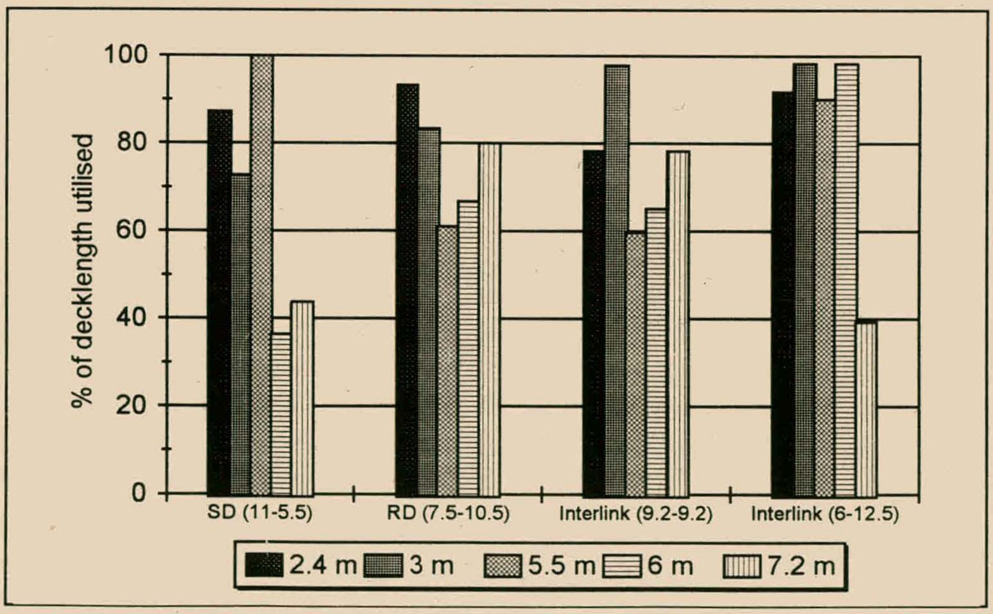
Dividing the various product lengths into the decklength available on each unit of the configuration (ignoring, for now, a tolerance between billets), revealed the following.

Table 4.2. The number of billets that can be carried on each of the decklength options identified.

Configuration (decklength)	2.4 m	3.0 m	5.5 m	6.0 m	7.2 m
SD (11-5.5)	6	4	3	1	1
RD (7.5-10.5)	7	5	2	2	2
Interlink (9.2-9.2)	6	6	2	2	2
Interlink (6-12.5)	7	6	3	3	1

To give more meaning to the data represented in this table, the percentage of available decklength occupied for each of the product lengths was determined and is graphically represented in Figure 4.1 below.

Figure 4.1. The percent decklength utilised for each product length and configuration decklength option.



An analysis of Figure 4.1 reveals the following:

- All configurations are suited to carrying 2.4 m lengths.
- The two interlink configurations are best suited to carrying 3.0 m lengths.
- The semitrailer-drawbar trailer is most suited to carrying 5.5 m lengths.
- The 6-12.5 interlink is ideally suited to carry both 5.5 m and 6.0 m lengths.
- The rigid-drawbar and 9.2-9.2 interlink configurations are most suited to carrying 7.2 m lengths.
- The 6-12.5 interlink was the most versatile configuration for transporting multiple length products.

4.2.2.3 Discussion

To facilitate loading and offloading operations, and to accommodate fluctuations in log length, hauliers usually allow a gap between billets. The shift to longer lengths, particularly 3.0 m and 6.0 m lengths, has caused this tolerance between the billets to disappear, necessitating more exact crosscutting to reduce overhang and interlocking of billets (which hampers offloading). The demands placed on the loader operator have also increased. Some hauliers have warned that the full utilisation of decklength, on particularly the 6-12.5 interlinks, can limit truck manoeuvrability on tight corners. As very little tolerance now exists between the two semitrailers, timber on the last billet of the front semitrailer can touch the timber on the front billet of the rear semitrailer, during cornering.

The move to longer lengths has had a positive effect on the tare mass of truck configurations as longer lengths require fewer uprights (bunks). A configuration carrying seven 2.4 m billets requires 14 uprights, collectively weighing approximately 1.89 tonnes (Exte logging bunks weigh 135 kg each). A move to 6.0 m lengths reduces the number of uprights to 6 and the combined weight of the uprights to 0.810 tonnes. This reduces the tare mass and adds another 1.08 tonnes of payload. If we were to use the base figures used in the economic comparison in Chapter Two, this 3% increase in payload has the potential to reduce transport costs by nearly 3%. The assumption is made that there is no reduction in the Solid Volume Factor due to the move to longer lengths, and the greater likelihood that mechanical loading may increase air spaces between the logs.

4.3 Product Density

4.3.1 Overview

Density is defined as the mass per unit volume of a material and the density of wood is typically expressed in kg/m^3. The mass of wood (or a log) includes both the oven-dry wood content and the mass of the water it contains. The volume of a log also varies with a change in moisture content. For this reason the density of wood can be expressed as:

As-received density	The as-received mass divided by the as-received volume.
Green density	The maximum swollen (green) mass divided by the maximum swollen (green) volume.
Basic density	The oven-dry mass divided by the maximum swollen (green) volume.
Oven-dry density	The oven-dry mass divided by the oven-dry volume. (TAPPI, 1985)

A further term commonly used with density is specific gravity. Specific gravity is the ratio of two densities - the density of wood and the density of pure water. In the metric system the numerical values for specific gravity and density are identical, as the density of pure water is taken as 1 (0.999973 g/cm^3 or 999.973 kg/m^3).

The density of pulpwood varies significantly. Basic density (and similarly oven-dry density) varies within the tree from top to bottom, from the inside to the outside, from one tree to the next, within the same species in the same compartment, between the same species on different geographic sites and with age and between species (Coetzee, 1984 and Stöhr, 1980). The significance of the density variation within a species has been illustrated by many authors. Local research by Schönau and Stubbings in 1981 indicated that the oven-dry density of *Eucalyptus grandis* pulpwood logs varied from 375 kg/m^3 to 520 kg/m^3, a difference of 38.7% (Coetzee, 1984).

Furthermore, the mass of a log declines significantly after felling, as moisture is lost during air drying. The rate at which moisture is lost depends on the species, whether the logs are debarked or not, the age of the log, its position in the stem, the log dimensions, its drying position (stacked or unstacked) and the season of felling and drying (Coetzee, 1984). Schönau (1989) demonstrated that the density of *E. grandis* declined by 29.5% from felling to 12 weeks air-dry due to moisture loss.

Coetzee (1984) concluded that, "Under normal forestry production situations wood density is in a continuous state of flux due to the factors affecting basic density and moisture content of timber". Accordingly, both Coetzee (1984) and Stöhr (1980) and numerous others, warn of the inherent dangers of using standard volume/mass conversion factors. Stöhr states that, "It seems highly unlikely that accurate mass/volume conversion figures can be established for any species". The use of standard conversion factors, however, is a common practice in the South African forest industry.

4.3.2 Pulpwood density and configuration considerations

In Chapter Two it became evident that to optimise transport costs payload has to be optimised. Significant variations in both the oven-dry density and as-received density of pulpwood, however, may prevent maximum payloads from being achieved, particularly in the less dense species and in very dry pulpwood.

To determine how product density affected the choice of configuration, a study of the interaction between pulpwood density and bulk volume of the four basic decklength types, discussed earlier, was undertaken.

4.3.2.1 Method

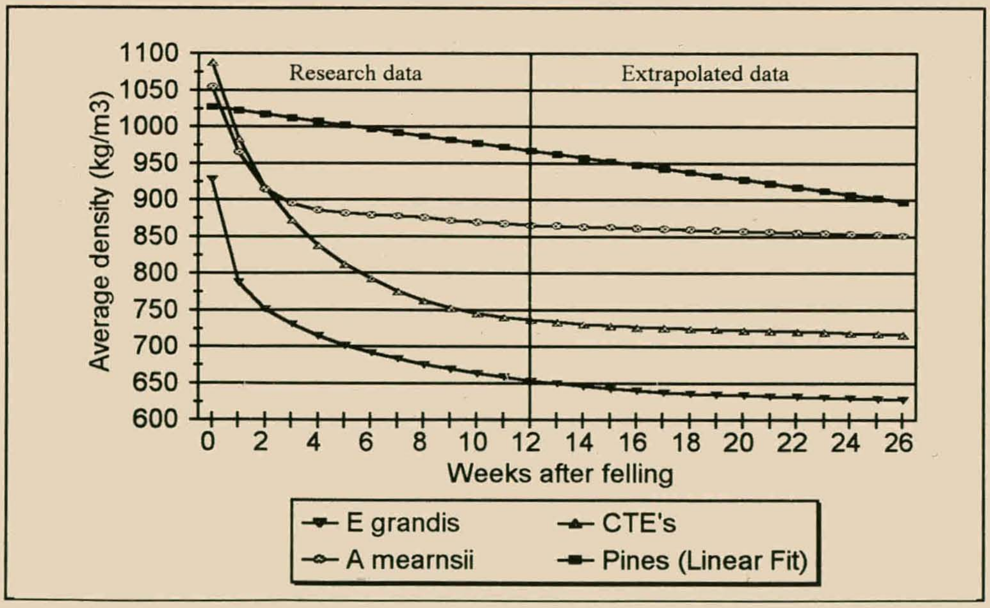
The average density decline (essentially as-received density), from felling to 12 weeks air-dried, was obtained for the most common pulpwood species in South Africa. Data for the hardwood species was obtained from the work of Schönau (1989) and for the softwood species from research conducted by Stöhr (1983). To simplify the study, species were grouped into four categories of similar densities (see Table 4.3 and Appendix Four page 104).

Table 4.3. The four species-density categories used in the study.

Category	Species
E. grandis	*Eucalyptus grandis*
Cold Tolerant Eucalypts (CTE's)	*E. macarthurii, E. fastigata, E. elata. E. nitens*
A. mearnsii	*Acacia mearnsii*
Pines	*Pinus patula, Pinus elliotii, Pinus taeda*

The decline in density for the four categories shown in Figure 4.2.

Figure 4.2. The density decline for the four species-density categories used in the study.



The density decline for some of the individual species can be seen in Figure 1.18 on page 19. Valid research data for the density decline after felling, for the selected species, was limited to roughly 12 weeks. To obtain data for the period from 12 weeks to 26 weeks (the typical upper age-after-felling mill requirement) the research data was theoretically extrapolated, according to the trend established during the last weeks of the research data. Limited research on the density decline after 12 weeks air-dry to the equilibrium density, necessitated this approach. It should be noted that researchers have smoothed the density decline curves and ignored the moisture gains (and thus density increases) induced by rainfall events.

From Figure 4.2 we can conclude the following for the period depicted:

- *E. grandis* has the lowest density.
- The moisture loss for *E. grandis*, the CTE's and *A. mearnsii* is dramatic, particularly in the first few weeks after felling.
- Pines lose moisture at a slow rate and have the highest density (primarily because they are undebarked and are very resinous).

It should be noted that pines have the lowest average oven-dry density of approximately 422 kg/m^3 (Stöhr, 1980). *E. grandis* has the second lowest (439 kg/m^3), followed by the CTE's (531 kg/m^3). *A. mearnsii* has the highest average oven-dry density of 667 kg/m^3 (Schönau, 1989).

As *E. grandis* has the lowest density and is most likely to limit the attainment of maximum payload (a concern often noted by hauliers), the study was limited to this species. It was also limited to 2.4 m lengths.

The bulk volume available on each of the four decklength options was derived from design drawings. It should be noted that many trailer manufacturers did not fully utilise the 4.3 m height allowance, due to concerns relating to stability. The bulk volume for each configuration was then divided by the volume/mass conversion factor (for each week after felling), derived from the average density data for the species. This figure was then multiplied by the recommended average Solid Volume Factor (SVF) for *E. grandis* (derived by Schönau and Boden, 1980) to determine the possible payload of solid wood on each configuration. An example of the procedure followed is described below:

Input data:	Bulk volume of configuration	= 110 m^3
	Density one week after felling	= 788 kg/m^3
	Conversion factor one week after felling	= 1.269 m^3/tonne
	SVF	= 0.7 (70%)
Calculation:	(Bulk volume/Conversion factor) x SVF	= Possible payload
	(110/1.269) x 0.7	= 60.68 tonnes

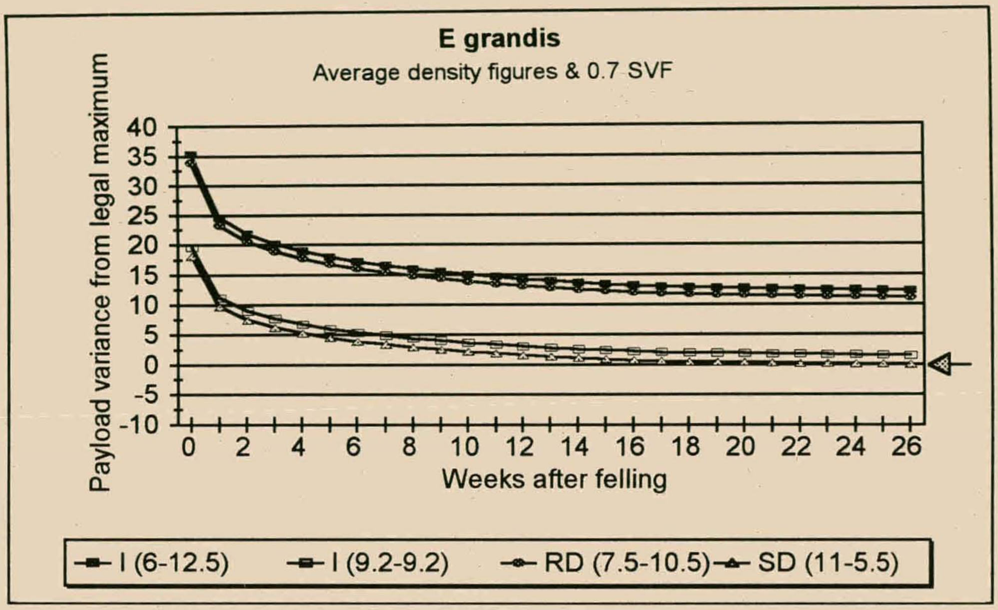
The maximum legal payload for each configuration was then obtained from Table 2.2 on page 37. Payload excluded the 5% tolerance allowed on the Gross Combination Mass. The legal payload was then subtracted from the possible payload (as derived in the above example) to determine if the density allowed maximum legal payloads to be achieved. The results for *E. grandis* and the four configurations are illustrated in Figure 4.3 (overleaf).

4.3.2.2 Results

The y-axis in Figure 4.3 depicts the payload variance (in tonnes) from the legal maximum. The zero line on the y-axis (see arrow) depicts the maximum legal payload. Data points above or on this line indicate that legal payloads are achievable. Data points below the line indicate that there is insufficient bulk volume to allow maximum payloads to be achieved with the density figures used.

When using the average density figures and average SVF for *E. grandis*, all configurations were able to achieve maximum payloads for the period studied. The additional bulk volume available on the seven billet configurations (I 6-12.5 and RD 7.5-10.5) meant that payloads, 10 tonnes above the legal payload, were achievable at 26 weeks after felling. The bulk volume available on the six billet configurations (I 9.2-9.2 and SD 11-5.5) resulted in the maximum payloads only just being achieved towards the end of the period.

Figure 4.3. The influence of density (and SVF) on the achievement of maximum legal payloads for the four configuration decklength options.



As the density figures and SVF used in the study are essentially averages of averages and estimates, and because of the significant known variation in density figures, a sensitivity analysis of the results was undertaken. First, the average densities were reduced by 10% (simulating, for example, a geographic variation in density). The SVF of 0.7 was retained. Next, the base densities were retained and the SVF reduced to 0.6 (simulating, for example, the effect of poor loading). The results are illustrated in Figures 4.4 and 4.5 (overleaf). See Appendix Four page 104 for calculations.

The results of the sensitivity analysis clearly illustrate that even minor changes to the base assumptions can have a significant effect. Changes to either the density figures or SVF resulted in the six billet configurations being unable to achieve maximum payloads, within a few weeks after felling. The seven billet configurations, however, were still able to achieve maximum payloads for the duration of the period studied.

Figure 4.4. The effect of reduced density figures (-10%) on the achievement of maximum payload for the four configuration decklength options.

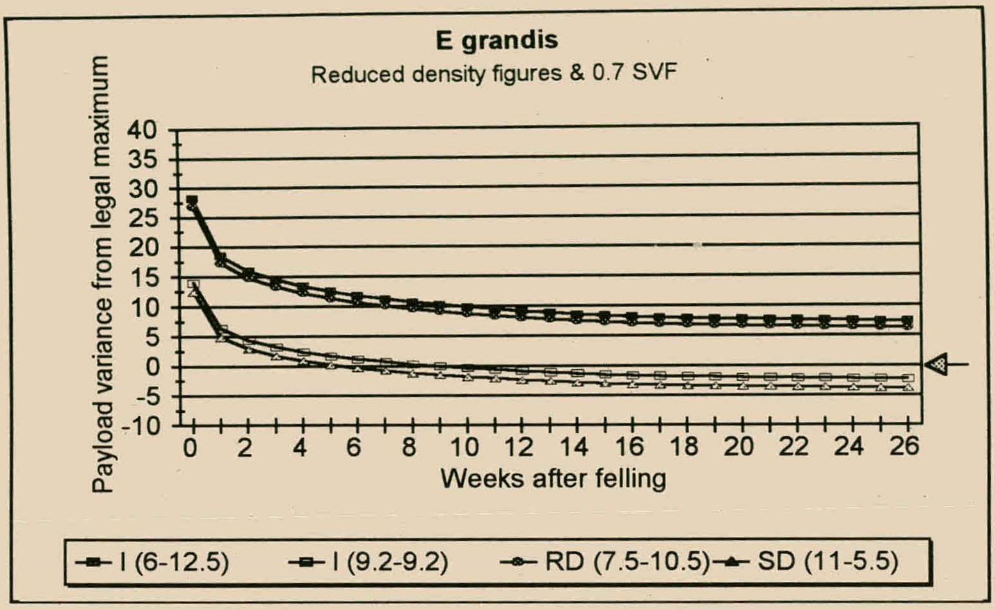
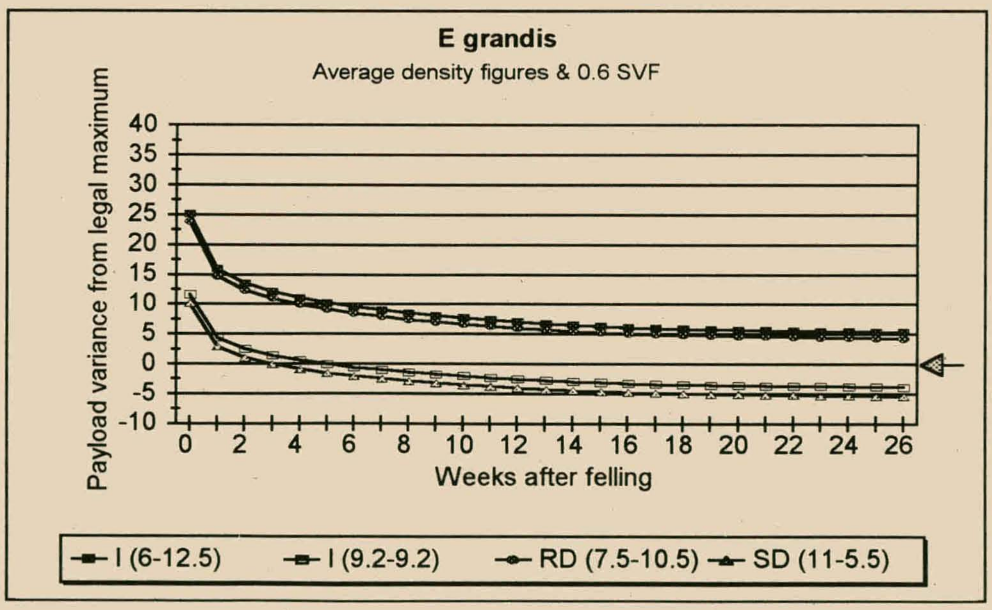


Figure 4.5. The effect of reduced SVF (0.6) on the achievement of maximum payloads for the four configuration decklength options.



4.3.2.3 Discussion

The additional bulk volume of the seven billet configurations allowed for a greater tolerance in the fluctuation of the density of *E. grandis* pulpwood. As densities vary significantly, operators transporting *E. grandis* pulpwood would benefit considerably by using configurations with additional bulk volume (ie. capable of carrying seven billets).

As *E. grandis* has by far the lowest density, it is unlikely that maximum payloads would not be achieved with the other species, during the period studied. When consistently transporting pulpwood beyond the 26 week limit required by the pulpmills, however, the additional volume of the seven billet configurations may be advantageous. It should be borne in mind that additional volume comes at the expense of additional decklength and uprights, and thus additional tare mass.

Configurations should be chosen that have the greatest potential payload and adequate bulk volume to consistently achieve the maximum legal payload, for the range of pulpwood densities being transported. Selecting configurations with excessive bulk volume, to cover the likelihood of carrying pulpwood with low densities (when mainly dense pulpwood is hauled), is not cost effective.

4.4 Conclusions

Research on the influence of pulpwood length and density on the selection of the most appropriate truck configuration has revealed that:

- The two interlink configurations (9.2-9.2 and 6-12.5 decklength options) are most suited to carrying 3.0 m logs.
- The semitrailer-drawbar trailer configuration was most suited to carry 5.5 m logs.
- The 6-12.5 interlink was ideally suited to carry 5.5 m and 6.0 m logs.

- The rigid-drawbar configuration and the 9.2-9.2 interlink were most suited to carrying 7.2 m logs.
- The 6-12.5 interlink was the most versatile configuration for transporting multiple length products.
- The move to longer lengths may inhibit manoeuvrability on the 6-12.5 interlink configuration.
- The move to longer lengths has the potential to significantly reduce the tare mass of configurations, as less uprights are required.
- *E. grandis* has the lowest as-received density of South African pulpwood species and is the species most likely to limit the achievement of maximum legal payloads.
- The bulk volume afforded by the seven (2.4 m) billet configurations may prove necessary when transporting *E. grandis* pulpwood and very dry pulpwood of the other species.
- The additional bulk volume of the seven billet configurations comes at the expense of additional tare mass.
- All configurations have sufficient bulk volume to allow legal payloads to be achieved for *A. mearnsii*, CTE's and Pines over the period studied.

4.5 Recommendations

- Pulpwood configurations should be selected for the product hauled, as the rule, not the exception.

- The highly variable density of pulpwood makes on-board weigh scales a necessity, to allow payloads to be consistently maximised and to avoid overloading penalties.

4.6 References

Coetzee J. 1984. **Volume as a unit of measurement of small dimension hardwood roundwood with particular emphasis on the requirements of the mining timber industry**. Wattle Research Institute, WRI Doc.11/84 Ref. D. 33/9.

Schönau A P G. 1989. **Average basic density, average volume/mass ratio and average moisture content on an air-dry basis for different drying periods of 2.5 m long debarked roundwood of six hardwood species**. Institute for Commercial Forestry Research, ICFR Document 4/1989.

Schönau A P G and Boden D I. 1980. **Solid timber volume of stacked *Eucalyptus grandis* pulpwood**. Reprint from the Wattle Research Institute Report for 1979-1980.

Stöhr H-P. 1980. **Initial moisture content and density and drying rate of three pine species growing in the Natal Midlands part 1: Moisture content and density of standing trees**. South African Forestry Journal, September 1980.

Stöhr H-P. 1983. **Initial moisture content and density and drying rate of three pine species growing in the Natal Midlands part 2: Drying rate and mass/volume conversion figures**. South African Forestry Journal, December 1983.

TAPPI. 1985. **Basic density and moisture content of pulpwood**. Technical Association of the Pulp and Paper Industry. Reference T 258 OM-85.

CHAPTER FIVE

The Merits and Limitations of Pulpwood Truck Configurations

5.1 Introduction

Previous chapters have assessed the economic performance, manoeuvrability, stability, tractive ability and the influence of the product on the selection of the most appropriate configuration for the longhaul of pulpwood. This chapter briefly assesses further configuration-specific limitations and then overviews the merits and limitations of each configuration type.

5.2 Payload Limitations

The results of the sensitivity analysis conducted in Chapter Two concur with the statement by Beardsell (1986) that, "Maximizing the legal payload every trip is seen as one of the most effective methods to reduce transport costs" (Shaffer *et al*, 1987).

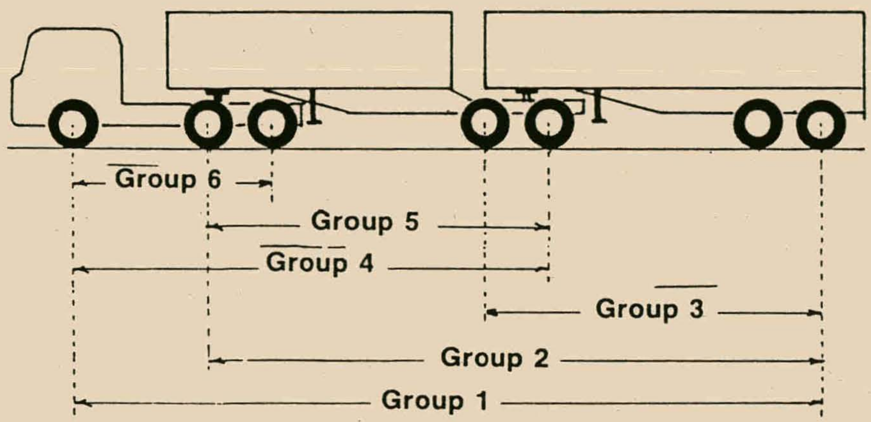
Determining maximum legal payload is essentially simple. It is the tare (or more appropriately unladen mass) subtracted from the Gross Combination Mass (GCM) of the configuration. A higher GCM and a lower tare mass will result in a greater payload. Under the regulations of the Road Traffic Act of 1989, there is no fixed upper GCM limit and the GCM for each configuration is determined according to the tyres, number of axles or axle units and the axle group spacings. GCM is thus influenced by a number of factors and can be limited by poor design. There is no legal limit to the tare mass. The attainment of maximum payload may be limited by the GCM in certain configurations and tare mass in others.

5.2.1 Gross Combination Mass limitations

GCM is limited to the least of either the sum of the axle massloads (Regulation 365), or the axle group massloads (Regulation 365A - the bridge formula).

The bridge formula ensures that the GCM of a vehicle is spread evenly across its length to limit possible damages to bridges. The formula allows for 2 100 kg of weight per running metre between the axle groups of the configuration, plus an additional 15 000 kg. The regulation applies to the six axle groups illustrated in Figure 5.1. The further apart the axles in each group, the greater the potential mass up to the point where the axle massload becomes the limiting factor. A contentious and often misunderstood regulation, it has the potential to lower the GCM and thus potential payload of configurations that are poorly designed.

Figure 5.1. The axle groups of the bridge formula.



To limit the constraints of the formula, trailer designers must ensure that the axles are optimally spaced. Some configurations are more easily penalised by the requirements of the bridge formula than others. Interlink configurations, for example, are less susceptible to the limitations of the formula than configurations with a drawbar trailer. Regulation 352 limits the distance between the two units of a configuration coupled by a drawbar to 2.0 m (underslung drawbars 2.5 m). This limitation often prevents the axles in axle group 5 (see above figure) from being spaced far enough apart, resulting in the bridge formula having the potential to limit maximum payload.

The GCM of configurations with eight axles tend to be limited by the bridge formula, as opposed to those with seven axles that are limited by the sum of the axle massloads (on a first to last axle basis). The reason for this is best explained by way of the following example.

A 7-axled interlink (I22-1222-2+5) with a 20 m first to last axle distance (L), will have a sum of the axle massloads of 55.7 tonnes (6.5+16.4+16.4+16.4), and a bridge formula GCM of 57 tonnes (2100 x 20 + 15000). A similar configuration with eight axles (I22-1232-2+5) will have a sum of the axle massloads of 60.3 tonnes (6.5+16.4+21+16.4) and a bridge formula GCM of 57 tonnes. If the least of each regulation is taken for each configuration, then the 8-axled configuration has a GCM 1.3 tonnes heavier than the 7-axled configuration (57-55.7 tonnes).

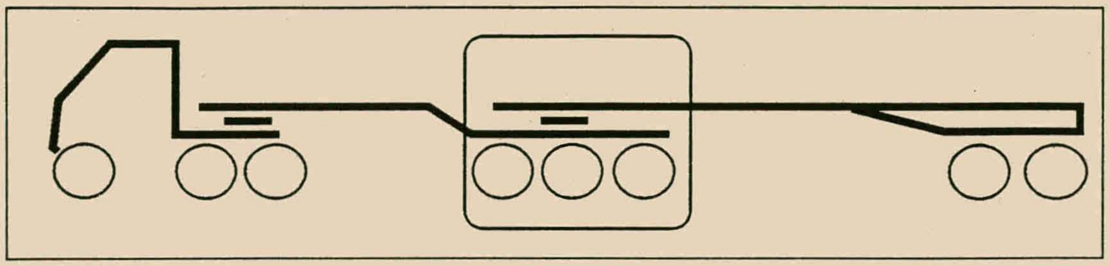
Even if the weight of the additional axle is added to the tare mass of the configuration, there is still a significant increase in payload. According to the manufacturers of these particular configurations, tare mass difference is only 0.4 tonnes. Payload thus increases by 0.9 tonnes due mainly to the greater GCM. The significance of this difference is illustrated by the ranking of the two configurations in the economic comparison discussed in Chapter Two (Table 2.2 page 37). The 8-axled configuration was ranked sixth and the 7-axle seventh.

5.2.2 Tare mass considerations

For each particular configuration the GCM is fixed. The only way that payload can be increased is to reduce the tare mass of the configuration. Tare mass is essentially reduced by using lighter construction materials and eliminating unnecessary components.

If the same construction materials (and truck-tractor) were used when constructing the three configuration types, the rigid-drawbar and semitrailer-drawbar configurations should always have a lighter tare mass than the interlink configuration. The reason for this is the excessive overlapping of the two semitrailers in the interlink configuration (see Figure 5.2). This overlapping has the advantage of providing additional decklength, but unfortunately at the expense of additional tare. Rigid-drawbar trailer configurations have no overlapping and have the added advantage of extending the length of the configuration with the least amount of steel, by way of an A-frame drawbar.

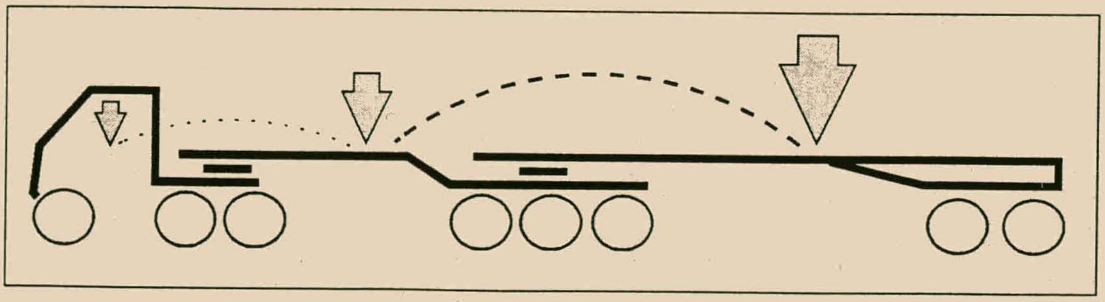
Figure 5.2. The overlapping of semitrailers on the interlink configuration.



5.3 Mass Transfer

An inherent drawback of configurations with semitrailers, and in particular interlinks, is the mass transfer between the units of the configuration. As a result of the overlapping of the units, any mass imposed on the rear of the second semitrailer will impose a portion of that mass onto the front semitrailer, which in turn imposes a portion of the mass on the truck-tractor (see Figure 5.3). This has the potential to unintentionally overload the steering axle and to complicate load distribution between the axles.

Figure 5.3. Mass transfer between the units of an interlink configuration.



5.4 Flexibility

An often cited advantage of configurations using independent truck-tractors (interlinks and semitrailers), is the ability to detach the truck-tractor and replace it with another should it become necessary. This flexibility is particularly convenient when truck-tractors have major breakdowns. An informal telephone survey revealed that the planned maintenance strategies of operators limited major truck-tractor breakdowns to roughly less than five per year. When calculating this as a percentage of the number of despatches, for a typical operators fleet over the course of a year, this equated less than 0.5% of total dispatches. Although this flexibility is undoubtably an advantage, it may not be significant.

5.5 Comparing the Merits and Limitations of Pulpwood Configurations

5.5.1 Overview

From the outset it is important to recognise that there are no right or wrong pulpwood configurations, only appropriate and inappropriate configurations. As operating requirements (product length and density, road conditions, etc) vary (even slightly), some configurations become more appropriate and others less so, mainly due to changes in the ranking of the criteria that influence the selection decision. Regardless, however, of the changes to the operating requirements, the cost per unit of payload, remains the most important determinant in the selection procedure. Therefore, criteria that influence the consistent achievement of maximum payload, will always carry more weight.

5.5.2 Method

To compare the relative performance of the four configuration decklength options against the criteria, assessed in this thesis, the profile method was used. Each configuration was assessed on a five point scale for each of the fifteen criteria identified. The scale used ranged from -2 to +2, with -2 being very bad, -1 being bad, 0 being indifferent, +1 being good, and +2 being very good. On completion of the relative comparison (each configuration relative to the others) the points were joined to give a profile for each configuration, for the fifteen criteria. The more the profile falls on the positive side of the scale, the better the relative performance of the configuration. It should be noted that all the criteria used in the assessment carried the same weight. The results of the comparison are shown in Table 5.1 on page 92.

5.5.3 **Results and discussion**

An analysis of the profiles for the different configurations reveals that:

- No configuration is scores positively for all the criteria, indicating that no single configuration is ideally suited to all operations.

- The profiles of the semitrailer-drawbar trailer and 9.2-9.2 interlink configurations fall more within the negative half of the table (13 negative to 8 positive and 10 negative to 9 positive points, respectively).

- The profiles of rigid-drawbar and 6-12.5 interlink configurations fall more within the positive half of the table (13 positive to 7 negative and 13 positive to 8 negative points, respectively).

Although the profiles may suggest that certain configurations perform better than others, it is important to remember that the individual criteria were not ranked (according to their importance) and the operating requirements were not specified. Consequently, a selection procedure to determine the most appropriate pulpwood truck configuration, requires that the profile data be coupled with a ranking of the criteria and a detailed understanding of the operating requirements. The development of such a selection procedure is discussed in Chapter Six.

Table 5.1. A comparison of the merits and limitations of the four configuration decklength options using the profile method.

Criteria	Interlink (6-12.5)					Interlink (9.2-9.2)					RD (7.5-10.5)					SD (11-5.5)				
	-2	-1	0	1	2	-2	-1	0	1	2	-2	-1	0	1	2	-2	-1	0	1	2
R/tonne transport cost	●								●					●						●
Offtracking and swept path		●					●							●						●
Reversibility					●					●				●		●				
Stability (potential to reduce CG)				●			●							●			●			
Tractive ability			●					●					●					●		
Product length versatility					●				●					●			●			
Suited to carry 3.0 m lengths					●					●	●					●				
Suited to carry 5.5 m lengths				●		●					●									●
Suited to carry 6.0 m lengths					●	●					●					●				
Suited to carry 7.2 m lengths	●									●					●	●				
Product density versatility					●		●								●		●			
High GCM potential			●					●				●					●			
Low tare mass potential		●					●								●				●	
Flexibility				●					●				●						●	
Load transfer between units	●					●									●		●			

5.6 Conclusion

As the operating requirements placed on a pulpwood transport operation change, so do the requirements placed on the truck configuration.

There is no single configuration ideally suited to all operations. Transport managers should, therefore, be aware of the merits and limitations of each configuration, to allow the selection of the most appropriate configuration for the job, enabling total transport costs to be minimised.

5.7 References

Shaffer R M, McNeel J F, Overboe P D and O'Rourke J. 1987. **On-board truck scales: Application to Southern timber harvesting**. Southern Journal of Applied Forestry (SJAF) 11(1987).

CHAPTER SIX

Selecting the Most Appropriate Pulpwood Truck Configuration

6.1 Introduction

If we assume that roads are given, the pulpwood truck configuration forms the foundation of any transport operation. To optimise the costs of longhaul pulpwood transport, therefore, we have to optimise those aspects related to the truck itself. Optimising peripheral aspects of transport, such as scheduling, monitoring and loading and offloading times, when using an inappropriate configuration, is obviously not ideal.

As there is considerable variation between pulpwood transport operations, in terms of product length, species density and terrain conditions, there should be considerable variation in the configuration most suited to each operation. To assist the transport manager in selecting the most appropriate configuration, a user friendly selection procedure has been developed (based on the preceding work in this thesis). The development of this procedure is described in this chapter.

6.2 Developing a Configuration Selection Procedure

It was stated in Chapter Five that any decision-making procedure to determine the most appropriate pulpwood truck configuration would require that the merits and limitations of the various configurations be ranked according to their importance and considered with the requirements of each operation.

6.2.1 Ranking the merits and limitations

The overriding objective of this configuration selection procedure is to minimise R/tonne transport costs. Therefore, the ranking of the configurations in the economic comparison of

Chapter Two, becomes a reference point for differentiating between possible configurations. Furthermore, as maximising payload has the greatest potential impact on transport costs, those criteria that influence the attainment of maximum achievable payload, will always carry more weight than the remaining criteria.

Of all the criteria in the selection procedure, ***product length*** is the primary determinant of the most appropriate configuration and thus carries the greatest weight. The greater the product length/decklength utilisation, the less wasted tare mass and the greater the potential payload. When product length does not favour any single configuration (and maximum payloads are achievable) the results of the economic comparison differentiate between configurations.

The next most important criteria is ***product density***. The configuration must have sufficient bulk volume to ensure that maximum payloads are achievable for the chosen species and for the age-after-felling range specified.

The third and fourth ranked criteria in the selection procedure relate to the condition of the forest road network. Unfavourable ***terrain*** conditions resulting in steep, winding and narrow roads, favour configurations that are more manoeuvrable, stable and that have better tractive ability. Poor ***road surface conditions*** (under all terrain conditions) favour configurations that have better tractive ability.

6.2.2 The operating requirements

Product length and density data used in the selection procedure are based on the conclusions of Chapter Four. Manoeuvrability, stability, and tractive ability data used are based on the conclusions of Chapter Three. Terrain and road surface conditions are specific for each transport operation and reflect those conditions likely to be encountered during the service life (or contract life) of the truck configuration.

A summary of the ranking of the selection criteria and the possible operating requirements can be found in Table 6.1.

Table 6.1. The ranking of the selection criteria and operating requirements used in the selection procedure.

<table>
<tr><th>Ranking</th><th>Criteria</th><th>Reason</th><th colspan="6">Operating requirements</th></tr>
<tr><td>1</td><td>Length</td><td>Length/decklength utilisation, payload</td><td>2.4 m</td><td>3.0 m</td><td>5.5 m</td><td>6.0 m</td><td>7.2 m</td><td>Multiple[1]</td></tr>
<tr><td rowspan="4">2</td><td rowspan="4">Density</td><td rowspan="4">Consistently achieve maximum payload</td><td colspan="6">Species group</td></tr>
<tr><td colspan="2">E. grandis</td><td>CTE's</td><td>A. mearnsii</td><td>Pines</td><td>Multiple</td></tr>
<tr><td colspan="6">Age-after-felling[2]</td></tr>
<tr><td colspan="2">< 3 months (fresh)</td><td colspan="2">>3 months (old)</td><td colspan="2">Both[3]</td></tr>
<tr><td>3</td><td>Terrain</td><td>Manoeuvrability/stability/tractive ability</td><td colspan="2">Flat</td><td colspan="2">Steep</td><td colspan="2">Both</td></tr>
<tr><td>4</td><td>Surface</td><td>Tractive ability[4]</td><td colspan="2">Good</td><td colspan="2">Poor</td><td colspan="2">Both</td></tr>
</table>

1 *Multiple log lengths excluding 7.2 m.*

2 *The age-after-felling has been divided into categories at the three month point, as a safety factor to account for the considerable variation in density.*

3 *When selecting the "both" category for age-after-felling, terrain and road surface condition, the configuration best suited to the worst condition will be selected.*

4 *Although an important criteria to be included in the selection procedure, limited research negates its influence on the results.*

6.2.3 Developing the selection procedure

Once the selection criteria had been ranked and the operating requirements specified, each possible combination of operating requirements was determined, using the method illustrated in Table 6.2, and the most appropriate configuration was selected.

Table 6.2. An example of the method used to develop the configuration selection procedure.

Length	Species	Age-after-felling	Terrain	Surface condition	Most appropriate configuration
2.4 m	E. grandis	< 3 months	Flat	Good	RD (7.5-10.5)
2.4 m	E. grandis	< 3 months	Flat	Poor	RD (7.5-10.5)
2.4 m	E. grandis	< 3 months	Flat	Both	RD (7.5-10.5)
2.4 m	E. grandis	< 3 months	Steep	Good	RD (7.5-10.5)
2.4 m	E. grandis	< 3 months	Steep	Poor	RD (7.5-10.5)
2.4 m	E. grandis	< 3 months	Steep	Both	RD (7.5-10.5)
2.4 m	E. grandis	< 3 months	Both	Good	RD (7.5-10.5)
2.4 m	E. grandis	< 3 months	Both	Poor	RD (7.5-10.5)
2.4 m	E. grandis	< 3 months	Both	Both	RD (7.5-10.5)
2.4 m	E. grandis	> 3 months	Flat	Good	RD (7.5-10.5)

The example in Table 6.2 shows a part the procedure used to select the most appropriate configuration for 2.4 m *E. grandis* pulpwood. As *E. grandis* is the least dense of all the pulpwood species and there is considerable variation in its density, the most cost effective 7 billet configuration (RD 7.5-10.5) was selected, as a safegaurd to ensure that maximum payloads are consistently achieved. Pulpwood density was therefore the determining factor for this range of operating requirements. For the remaining species and operating requirements, the overiding influence of pulpwood length soon became apparent during the development of the selection procedure. The configuration selection procedure results are shown in Table 6.3.

Table 6.3. The configuration selection procedure.

Pulpwood length	Species category	Age-after-felling	Terrain	Surface condition[3]	Configuration[1]	
					Most appropriate	Possible alternative[2]
2.4 m	E. grandis	All	All	All	RD (7.5-10.5)	Interlink (6-12.5)
	CTE's, A. mearnsii, Pines	< 3 months	All	All	SD (11-5.5)	Interlink (9.2-9.2)
		All	All	All	RD (7.5-10.5)	Interlink (6-12.5)
3.0 m	All	All	All	All	Interlink (9:2-9.2)	Interlink (6-12.5)
5.5 m	All	All	All	All	SD (11-5.5)	Interlink (6-12.5)
6.0 m	All	All	All	All	Interlink (6-12.5)	-
7.2 m	All	All	Flat	All	Interlink (9.2-9.2)	RD (7.5-10.5)
			All	All	RD (7.5-10.5)	Interlink (9.2-9.2)
Multiple	All	All	All	All	Interlink (6-12.5)	-

1 *Configuration codes used in this table relate to the decklength options identified in Table 4.1 page 73.*

2 *Choosing the alternative configuration may come with a R/tonne cost penalty, the significance of which is determined by the user.*

3 *Limited research findings negate the influence of this important criteria in the selection procedure.*

6.2.4 Results

An analysis of the results of the configuration selection procedure, tabled on the preceding page, reveals the following:

- No single configuration is favoured and all three configuration types are well represented.

- Product length is the primary determinant of the most appropriate configuration and often negates the influence of the remaining criteria in the procedure.

- Possible alternatives exist for most of the operating requirements. Selecting these alternatives may come with a R/tonne, manoeuvrability, stability or tractive ability penalty. Quantifying the R/tonne penalty is easily done by referring to the results of the economic comparison (Table 2.2 page 37). This penalty ranges from R 0.14/tonne to R 1.41/tonne. Quantifying the effects of reduced manoeuvrability and stability are more difficult and are made more subjective due to limited research findings.

- The 6-12.5 interlink configuration is the only configuration capable of carrying 6.0 m and multiple pulpwood lengths.

6.2.5 Discussion

The importance of product length in the selection procedure is self evident. As the primary determinant of the most appropriate configuration, it may be worthwhile to discuss the implications of the chosen pulpwood length on the cost of longhaul transport.

It was previously stated that the move to longer lengths in the pulpwood industry were initiated to reduce harvesting and handling costs. Longer lengths required less crosscutting and facilitated quicker loading and offloading times. A further advantage of moving to longer lengths was the savings in tare mass due to the need for less uprights. Disadvantages associated with longer lengths, however, are that they are best suited to mechanised operations as manual handling becomes physically more demanding as lengths increase. Longer lengths are also more prone to reduce the solid wood content of a load, as the likelihood of air spaces increases with increasing log length. A further disadvantage associated with moving longer lengths is highlighted by the results of the selection procedure (and is best illustrated by way of the following example).

A haulier transporting 6.0 m logs is limited to using the expensive 6-12.5 interlink, as it is the only configuration suited to carry this length. If the haulier was to transport 3.0 m logs instead, he could reduce transport costs by R 1.27/tonne (or 5.8%) if he used the 9.2-9.2 interlink. It should be noted that this reduction in costs, however, may not outweigh the advantages of hauling 6.0 m logs but has invariably not been considered in the justification to move to longer lengths. The above example suggests that either the move to 6.0 m lengths be reviewed or the design of an alternative, more cost effective configuration capable of carrying 6.0 m lengths be investigated.

The operational and cost implications of a chosen pulpwood length go beyond the discussions relevant to this thesis. In addition to those points discussed, the move to longer lengths has the potential to increase fibre wastage (as the likelihood of discarding merchantable pulpwood increases, as pulpwood length increases, if the utilisable tree length is not easily divisible by the longer length) and may necessitate considerable capital expenditure to upgrade or modify mill woodyard handling facilities. The chosen pulpwood length, therefore, does not only influence transport costs, but impacts all costs from stump to mill woodyard.

6.2.6 Further developments

To eliminate the use of subjective input data, the configurations analised in the economic comparison (Chapter Two) and subsequently used the selection procedure were limited to those for which costs and design drawings were obtainable at the time of the longhaul pulpwood survey (March-April 1995).

An increasing trend towards the transport of longer pulpwood logs (particularly 6.0 m hardwood logs which currently account for only 1.95% of pulpwood hauled), a re-assessment of the merits of the dominant interlink configuration and the results of the selection procedure described in this chapter, have encouraged further developments in configuration design since the survey.

The need to design a more cost effective and manoeuvrable configuration capable of carrying 6.0 m (and multiple) lengths to replace the 6-12.5 interlink has prompted the forest industry to assess the feasibility of a rigid-drawbar configuration capable of carrying three 6.0 m lengths. Initial design drawings indicate that such a configuration (RD 6-12) is possible within the regulations of the Road Traffic Act and provisional economic analysis indicate that this configuration has the potential to replace both the I 6-12.5 and RD 7.5-10.5 configurations in the selection procedure. Although at an early stage of development preliminary results suggest that this configuration may challenge the dominance of the interlink configuration in the longhaul transport of pulpwood in the South African forest industry.

Further encouraging developments in the industry have been the launch of many new light-weight Scandinavian, European and American truck-tractor models and the purchase of light-weight Scandinavian pulpwood trailers to compete with the somewhat dated and conservative technologies of local trailer manufacturers. It appears that the forest industry has realised the importance of maximising payload by focusing on reducing the tare mass of its configurations.

6.2.7 **Conclusion**

The results of the configuration selection procedure confirm that no single configuration is ideally suited to all longhaul transport operations. The predominance of the interlink configuration (accounting for 88.57% of all configurations surveyed) and recent developments in configuration design may suggest that inappropriate truck configurations are being used to transport pulpwood. Selecting the most appropriate truck configuration, using the configuration selection procedure described in this chapter, has the potential to significantly reduce transport costs by optimising costs at their source.

6.3 Concluding Remarks

To optimise the longhaul transport of pulpwood the South African forest industry must:

- Be aware of the merits and limitations of the various truck configurations and select the most appropriate configuration for the operational requirements to be encountered during the service or contract life of the configuration.

- Select the configuration for the rule not the exception.

- Obsessively and continuously pursue a programme to reduce the tare mass of configurations. This includes both the truck-tractor and trailer.

- Consistently maximise legal payload by fitting load cell on-board weigh scales to configurations.

- Identify and focus on those variables that have the greatest potential impact on the R/tonne cost of transport.

- Combine the aforementioned requirements with benchmarked transport management practices, to optimise the peripheral aspects of transport.

APPENDIX ONE

1995 South African Pulpwood Transport Survey Questionnaire

South African Pulpwood Transport Survey

1995

Undertaken by:

Forest Engineering Technology Section
Faculty of Forestry
University of Stellenbosch
Private Bag X1
Matieland
7602

SECTION 1 COMPANY OVERVIEW

Question 1.1 General information

Company name	
Area of responsibility (depot/region)	

Question 1.2 What is the average annual tonnage of pulpwood your company/depot/region transports?

Average annual tonnes transported	

Question 1.3 What is the percentage split between hardwood and softwood?

Hardwood (%)	
Softwood (%)	

Question 1.4 What is your weighted average transport lead (one-way) distance?

0 - 50 km	
51 - 100 km	
101 - 150 km	
151 - 200 km	
201 - 250 km	
> 250 km	

Question 1.5 What *percentage* of the timber is moved in the following lengths?

2.4 m	
3.0 m	
5.5 m	
6.0 m	
Other	

Question 1.6 How many *customers* (forest companies, co-ops, etc) do you transport pulpwood for?

1	
2	
3 or more	

Question 1.7 How many *markets* (Saiccor, Merebank, etc) do you transport pulpwood to?

1	
2	
3 or more	

Question 1.8 Does your company/region/depot transport

only pulpwood?	
pulpwood and sugar cane on the same trailers?	
pulpwood and other products on the same trailers?	

Question 1.9 What is the average duration of your contracts?

No contracts	
1 year	
2 years	
3 years	
4 years	
5 years	

Question 1.10 How are you paid?

R/tonne	
R/km	

SECTION 2 LOADING

Question 2.1 What *percentage* of your pulpwood is loaded at

large, constructed, centralised depots?	
small, informal depots or landings?	
roadside?	

Question 2.2 What *percentage* of your pulpwood is loaded by

own loaders?	
customer loaders?	
contract loaders?	

Question 2.3 What *percentage* of your pulpwood is loaded by the following machines?

Three-wheel loaders (eg Bell Loggers)	
Front-end loaders	
Knuckle-boom loaders	
Bundle loaders (Zulu crane)	
Heel-boom loaders	

Question 2.4 How is the loaded timber orientated?

Longitudinally (same direction as truck)	
Transversally (90 degrees to truck)	

Question 2.5 What is your average payload?

Average payload (tonnes)	

SECTION 3 FLEET CHARACTERISTICS

Question 3.1 What tyres do you *mainly* fit to your trailers?

Duals	
Super singles	
Singles	

Question 3.2 What suspension systems are *mainly* fitted on your trailers?

Parabolic	
Steel leaf spring	
Air bag	

Question 3.3 How many trucks are fitted with the following on-board weigh scales?

Load cells (measure shear of load-bearing steel bar)	
Non load-bearing scales (transducers which measure the deflection of a load-bearing component)	
Air-bag suspension load scales	

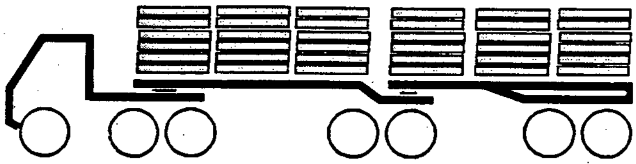
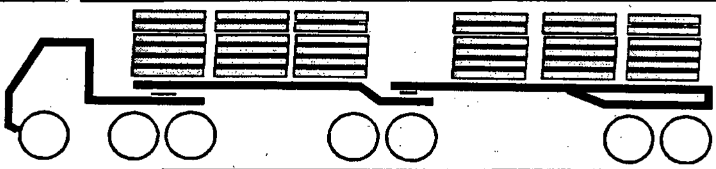
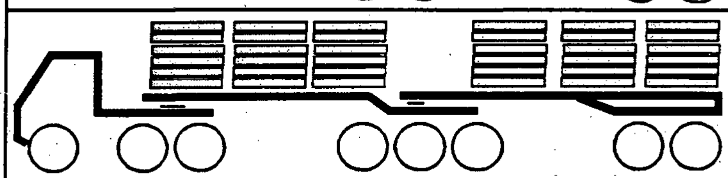
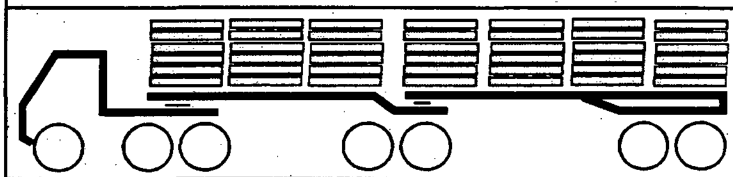
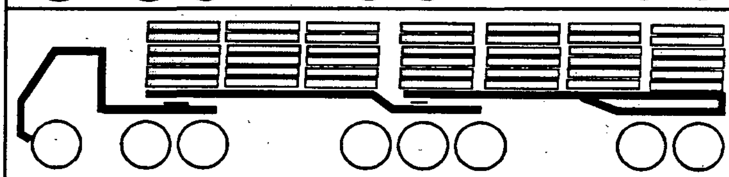
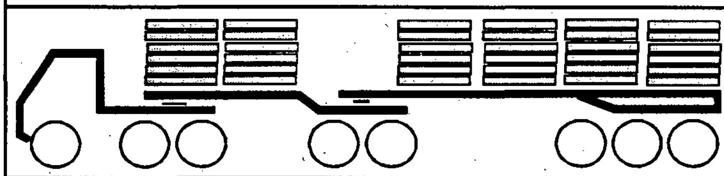
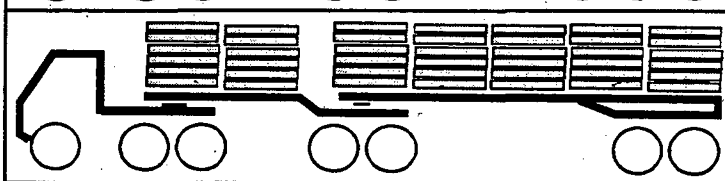
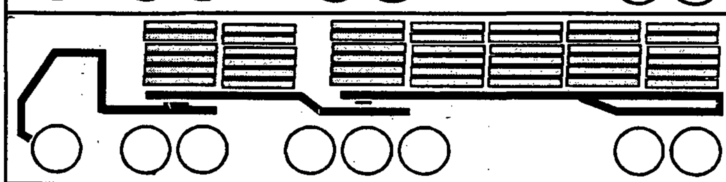
Question 3.4 How accurate are they?

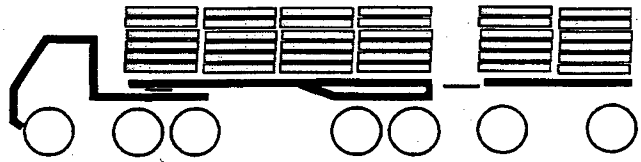
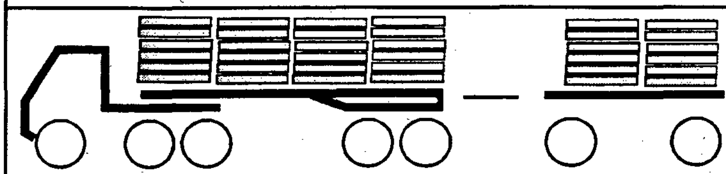
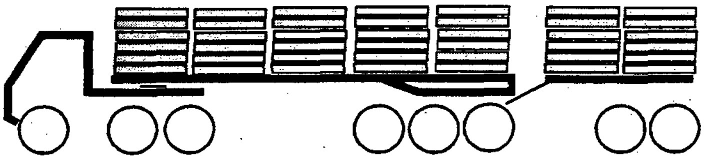
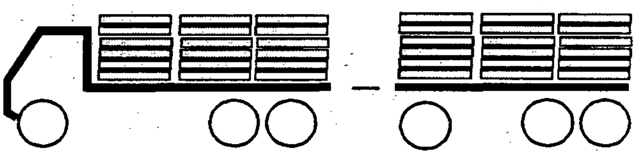
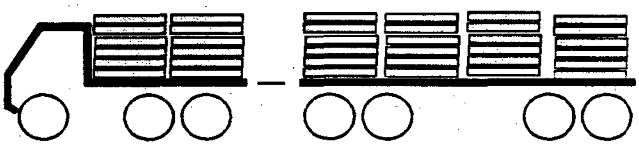
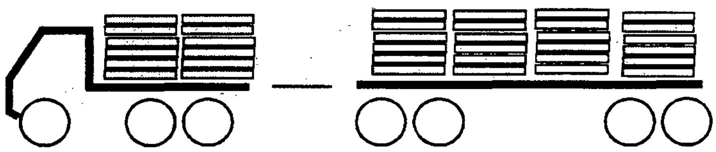
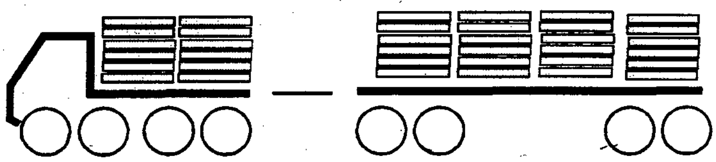
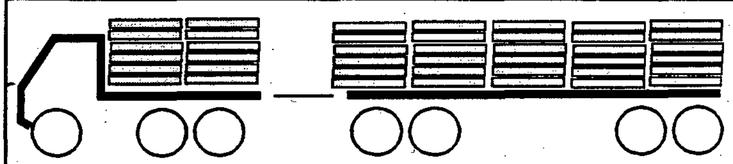
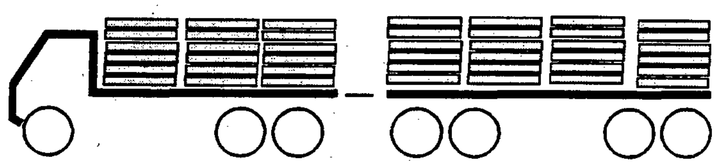
Very accurate (within 1% of GCM)	
Acceptable (do the job)	
Very inaccurate (give unreliable readings)	
Do not work	

Question 3.5 What precautions do you take to prevent spillage from the rear billets of your trailers?

Tailboards	
Nets	
None	

Question 3.6 How many of the following configurations do you actively use to transport pulpwood? (Short configurations 20 m, longer configurations 22 m)

Interlinks	Number	Ave tare (t)
		
		
		
		
		
		
		
		

Semi and drawbar trailers	Number	Ave tare (t)
		
		
		
Rigid trucks and drawbar trailers	**Number**	**Ave tare (t)**
		
		
		
		
		
		

Question 3.7 How many of your trailers are

< 3 years old? (constructed 1992/93/94)	
4 - 10 years old?	
> 10 years old?	

Question 3.8 How many truck-tractors do you own?

Manufacturer	Model	Year	Number
Mercedes Benz			
MAN			
ERF			
Others			

SECTION 4 **MANAGEMENT**

Question 4.1 How many *operational* transport managers does your company/region/depot employ with the following qualifications?

Commerce degree specialising in transport	
Engineering degree specialising in transport	
Diploma in transport management	
Mechanical qualifications with experience in transport	
Forestry qualifications with experience in transport	
Qualified by experience	

I would like to sincerely thank you for taking the time to complete this survey questionnaire. The information you have provided will be treated with the utmost confidence and will not be used in such a manner that individual companies can be identified.

Should you have any queries please do not hesitate to contact Russell Morkel at 021 8083589.

APPENDIX TWO

1995 South African Pulpwood Transport Survey Results

1.1 Company	Company 1			Company 2			Company 3	Company 4	Company 5	Company 6	Company 7	Company 8	Company 9	Company 10	Total	Percent
Region/depot	Depot A	Depot B	Total	Depot A	Depot B	Total										
Response (1)	1	1	2	1	1	2	1	1	1	1	1	1	1	1	**12**	
1.2 Annual tonnes	299000	110000	409000	440000	150000	590000	681313	240000	620000	72000	108000	50000	125000	180000	**3075313**	**64.55**
1.3 Hardwood (%)	70	68.2		60	80		70	10		100		100	10	90		
Softwood (%)	30	31.8		40	20		30	90	100		100		90	10		
Hardwood	209300	75020	284320	264000	120000	384000	476919.1	24000	0	72000	0	50000	12500	162000	1465739	**47.66146**
Softwood	89700	34980	124680	176000	30000	206000	204393.9	216000	620000	0	108000	0	112500	18000	1609574	**52.33854**
1.4 0-50 km		1	1			0					1				2	
51-100 km			0			0			1						1	
101-150 km	1		1	1	1	2	1						1		5	
151-200 km			0			0				1				1	2	
201-250 km			0			0		1				1			2	
>250 km			0			0									0	
															121.3581	Theory
Actual (if given)	120	29		138	105		130	230	66	160	14	210	125	175	**120.6016**	Actual
1.5 2.4 m (%)	100	100		45	60		85	100	80	100	37.03704	100	100	100		
3.0 m (%)				55												
5.5 m (%)							15									
6.0 m (%)					40											
Other (%)									20		62.96296					
2.4 m	299000	110000	409000	198000	90000	288000	579116.05	240000	496000	72000	40000.003	50000	125000	180000	2479116	80.61345
3.0 m	0	0	0	242000	0	242000	0	0	0	0	0	0	0	0	242000	7.869118
5.5 m	0	0	0	0	0	0	102196.95	0	0	0	0	0	0	0	102197	3.32314
6.0 m	0	0	0	0	60000	60000	0	0	0	0	0	0	0	0	60000	1.951021
6.6-7.2 m	0	0	0	0	0	0	0	0	124000	0	67999.997	0	0	0	192000	6.243267
1.6 1		1	1			0					1	1	1		4	33.33333
2			0			0			1						1	8.333333
3+	1		1	1	1	2	1	1		1				1	7	58.33333
1.7 1			0			0					1				1	8.333333
2		1	1			0		1	1				1		4	33.33333
3+	1		1	1	1	2	1			1		1		1	7	58.33333
1.8 Pulpwood		1	1		1	1	1				1	1	1		6	50
Pulp&sugar	1		1	1		1									2	16.66667
Pulp&other			0			0		1	1	1				1	4	33.33333
1.9 No contract	0.333333		0.333333			0						1	1		2.333333	19.44444
1 year	0.333333		0.333333			0				1				1	2.333333	19.44444
2 years			0			0									0	0
3 years	0.333333	1	1.333333	1		1	1	1							4.333333	36.11111
4 years			0		1	1			1		1				3	25
5 years			0			0									0	0

1.10	R/tonne	1	1		0.5	0.5		0.5	0.5	0.5	1	0.5			1		
	R/km				0.5	0.5		0.5	0.5	0.5		0.5					
2.1	Large depots (%)	99			5	80		45	85	75	40				30		
	Depots/landings (%)	1			95	10		55	15	10	60	89.814815	100	100	60		
	roadside (%)		100			10				15		10.185185			10		
	Large depots	296010	0	296010	22000	120000	142000	306590.85	204000	465000	28800	0	0	0	54000	1496401	48.65849
	Depots/landings	2990	0	2990	418000	15000	433000	374722.15	36000	62000	43200	97000	50000	125000	108000	1331912	43.30981
	Roadside	0	110000	110000	0	15000	15000	0	0	93000	0	11000	0	0	18000	247000	8.031703
																3075313	
2.2	Own loaders (%)	35	100		40	10			50	90	100		100	75	50		
	Customer loaders (%)	65				10									50		
	Contract Loaders(%)				60	80		100	50	10		100		25			
	Own loaders	104650	110000	214650	176000	15000	191000	0	120000	558000	72000	0	50000	93750	90000	1389400	45.17914
	Customer loaders	194350	0	194350	0	15000	15000	0	0	0	0	0	0	0	90000	299350	9.733969
	Contract loaders	0	0	0	264000	120000	384000	681313	120000	62000	0	108000	0	31250	0	1386563	45.08689
																3075313	
2.3	Three-wheel (%)	100	66.6		100	100		85	100	100	100	100	90	30			
	Front-end (%)													40			
	Knuckle-boom (%)		33.4					15					10		100		
	Bundle (%)													30			
	Three-wheel	299000	73260	372260	440000	150000	590000	579116.05	240000	620000	72000	108000	45000	37500	0	2663876	86.6213
	Front-end	0	0	0	0	0	0	0	0	0	0	0	0	50000	0	50000	1.625851
	Knuckle-boom	0	36740	36740	0	0	0	102196.95	0	0	0	0	5000	0	180000	323937	10.53346
	Bundle	0	0	0	0	0	0	0	0	0	0	0	0	37500	0	37500	1.219388
																3075313	
2.4	Longitudinally	1	1	2	1	1	2	1	1	0.5	1	1	1	1	1	11.5	95.83333
	Transversely			0			0			0.5						0.5	4.166667
2.5	Average payload	34	26		36	35		36	37	35.5	29	38	35	31	38	**35.18025**	
3.1	Duals	1	1	2	0.5	0.5	1	1		0.5	0.8		1	1	1	8.3	69.16667
	Super singles			0			0		1							1	8.333333
	Singles			0	0.5	0.5	1			0.5	0.2	1				2.7	22.5
3.2	Parabolic	3		3			0				3					6	2.857143
	Steel leaf spring	10	5	15	30	8	38	27	15	10	8		3	12	55	183	87.14286
	Air bag	7		7			0			10	1	3				21	10
																210	
3.3	Load cell			0			0	22					3			25	42.37288
	Transducer			0	1		1									1	1.694915
	Air-bag + load cell	20		20			0			10		3				33	55.9322
																59	**28.09524**
	Load cells (%)	0	0	0	0	0	0	81.481481	0	0	0	0	100	0		11.90476	
	Transducers (%)	0	0	0	3.333333	0	2.631579	0	0	0	0	0	0	0		0.47619	
	Load cell + airbag (%)	100	0	80	0	0	0	0	0	50	0	100	0	0		15.71429	

3.4	Very accurate			0			0			10			3			13	22.0339
	Acceptable	20		20	1		1					1.5				22.5	38.13559
	Very inaccurate			0			0									0	0
	Do not work			0			0	22	0			1.5				23.5	39.83051
																59	
3.5	Tailbords	20		20	15	4	19	9			6					54	25.71
	Nets			0	15	4	19	9	15	20	6		3			72	34.29
	None (strapping)		5	5			0	9				3		12	55	84	40.00
																210	
																	% config
3.6	I20-1222-3+3			0			0		11	5	5			8	39	68	36.56
	I22-1222-3+3			0	14	4	18									18	9.68
	I22-1232-3+3			0			0			10		3				13	6.99
	I22-1231-4+2			0			0				1					1	0.54
	I22-1222-3+4	7		7			0	5			1					13	6.99
	I22-1232-3+4	11		11			0				5					16	8.60
	I22-1223-2+4			0			0						3			3	1.61
	I22-1222-2+5	1		1		2	2	22							16	41	22.04
	I22-1232-2+5			0	11	2	13									13	6.99
	Total Interlinks	19	0	19	25	8	33	27	11	15	12	3	3	8	55	**186**	
	% of total	95	0	76	83.33333	100	86.84211	100	73.333333	75	100	100	100	66.666667	100	**88.57**	
	SD20-12211-4+2			0			0			2						2	14.29
	SD22-12211-4+2			0	5		5		3					4		12	85.71
	SD22-1232-5+2			0			0									0	0.00
	Total semi/drawbar	0	0	0	5	0	5	0	3	2	0	0	0	4	0	**14**	
	% of total	0	0	0	16.66667	0	13.15789	0	20	10	0	0	0	33.333333	0	**6.67**	
	RD20-1212-3+3		5	5			0			3						8	80.00
	RD20-1222-2+4	1		1			0									1	10.00
	RD22-1222-2+4			0			0									0	0.00
	RD22-2222-2+4			0			0									0	0.00
	RD22-1222-2+5			0			0		1							1	10.00
	RD22-1222-3+4			0			0									0	0.00
	Total rigid/drawbar	1	5	6	0	0	0	0	1	3	0	0	0	0	0	**10**	
	% of total	5	100	24	0	0	0	0	6.6666667	15	0	0	0	0	0	**4.76**	
	TOTAL CONFIGS	20	5	25	30	8	38	27	15	20	12	3	3	12	55	**210**	
										22m long	**62.38**		7billet%	**40**		**21.90**	
3.7	< 3years	20		20	11	4	15	19	3	10	7	3	3		16	96	
	4 - 10 years		5	5		4	4	8	12	10	5			4	39	87	
	> 10 years			0	19		19							8		27	
	Total	20	5	25	30	8	38	27	15	20	12	3	3	12	55	210	
	Variance	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	< 3years (%)	100	0	80	36.66667	50	39.47368	70.37037	20	50	58.333333	100	100	0	29.090909	45.71429	
	4 - 10 years (%)	0	100	20	0	50	10.52632	29.62963	80	50	41.666667	0	0	33.333333	70.909091	41.42857	
	> 10 years (%)	0	0	0	63.33333	0	50	0	0	0	0	0	0	66.666667	0	12.85714	
3.8	MB2632			0	15	4	19	14	4							37	24.50331
	MB2635	13		13			0								5	18	11.92053
	MB2636		5	5	6	4	10	8	11		1		3	3	4	45	29.80132
	MB2637	7		7			0		1	10	1					19	12.58278

MB2638			0			0			5						5	3.311258
MB2628			0			0			2						2	1.324503
MB2629			0			0			3						3	1.986755
MAN30380			0			0							2		2	1.324503
MAN26402			0			0				1					1	0.662252
MAN30440			0			0								4	4	2.649007
MAN26372			0			0				4	3				7	4.635762
ERF480T1			0			0						1			1	0.662252
Mack686B			0			0							7		7	4.635762
Total	20	5	25	21	8	29	22	16	20	7	3	4	12	13	**151**	
Year																
1975			0			0		1							1	0.662252
1976			0			0									0	0
1977			0			0									0	0
1978			0			0								1	1	0.662252
1979			0			0		1					2		3	1.986755
1980			0	3		3	3						2		8	5.298013
1981			0	4		4	3	1						1	9	5.960265
1982			0	5		5	3	1						1	10	6.622517
1983			0	3		3	3							1	7	4.635762
1984			0	6	4	10	2						3	1	16	10.59603
1985			0			0		1					2	1	4	2.649007
1986			0			0			2				1	1	4	2.649007
1987			0			0								1	1	0.662252
1988		5	5			0		1						1	7	4.635762
1989			0			0	2	2	5				1	4	14	9.271523
1990			0			0	2	5		5		3	1		16	10.59603
1991			0		4	4	2								6	3.97351
1992			0			0	2	2	10						14	9.271523
1993			0			0					3				3	1.986755
1994	20		20			0		1	3	2		1			27	17.88079
1995			0			0									0	0
Total	20	5	25	21	8	29	22	16	20	7	3	4	12	13	**151**	**7.40**
4.1 Commerce			0			0			1						1	
Engineering	1		1	1		1						1			3	
Diploma	20	1	21	1	1	2	2	1	2			1		2	31	
Mechanical	11		11			0		1	1	2	1	1	1		18	
Forestry			0			0	1		1					1	3	
QBE	29	1	30			0	1		3		1	1			36	
Total	61	2	63	2	1	3	4	2	8	2	2	4	1	3	**92**	
Commerce (%)	0	0	0	0	0	0	0	0	12.5	0	0	0	0	0	1.086957	
Engineering (%)	1.639344	0	1.587302	50	0	33.33333	0	0	0	0	0	25	0	0	3.26087	
Diploma (%)	32.78689	50	33.33333	50	100	66.66667	50	50	25	0	0	25	0	66.666667	33.69565	
Mechanical (%)	18.03279	0	17.46032	0	0	0	0	50	12.5	100	50	25	100	0	19.56522	
Forestry (%)	0	0	0	0	0	0	25	0	12.5	0	0	0	0	33.333333	3.26087	
QBE (%)	47.54098	50	47.61905	0	0	0	25	0	37.5	0	50	25	0	0	39.13043	

Appendix Three

Examples of Logtran II Reports

Input Data and Operation Description

Operational Data

Trip roundup value	0.750	[0.0 - 1.0]
Average payload	35.3	tons
Speed - empty	55.0	km/h
- full	33.0	km/h
Loading time	1.1	min/ton + 25.0 min fixed = 63.9 min
Unloading time	0.5	min/ton + 20.0 min fixed = 37.7 min
Working days/week	6.5	(333.0 days/year)
Length of workday	1440.0	min
Delays & breaks	288.0	min
Effective workday	1152.0	min
Required throughput	80.0	tons/day

Cost Data - FIXED Costs

Labour cost	R 100.00	
Purchase price	R 711000.00	
Salvage value	R 284400.00	
Expected lifespan	6.0	years
Interest rate	18.00	%
Insurance costs	R 71100.00	/year
License costs	R 5497.00	/year
Administration	6.000	% of total costs

Cost Data - VARIABLE Costs

Fuel consumption	60.00	l/100km
Fuel price	1.4930	R/l
Oil costs as % of fuel	2.50	% of fuel costs
Estimated tyre life	60000	km
Number of tyres	20	
Cost per tyre	R 1400.00	
Cost of spares	30.0000	c/km
Cost of workshop	10.0000	c/km

LOGTRAN II v1.0 (C) 1991 CSIR

Manager (SAPPI) Forestry Engineering

L O G T R A N R U N

D a i l y P r o d u c t i o n f o r S i n g l e V e h i c l e

DIST	*--------- CYCLE TIME (mins) --------*					*--- MAXIMUM --*			*- REQUIRED -*	
(km)	LOAD	FULL	UNLOAD	EMPTY	TOTAL	TRIPS		TONS	TRIPS	TONS
100.0	63.9	181.8	37.7	109.1	392.4	2.94	3	106.0	3.0	106.0
101.0	63.9	183.6	37.7	110.2	395.3	2.91	3	106.0	3.0	106.0
102.0	63.9	185.5	37.7	111.3	398.3	2.89	3	106.0	3.0	106.0
103.0	63.9	187.3	37.7	112.4	401.2	2.87	3	106.0	3.0	106.0
104.0	63.9	189.1	37.7	113.5	404.1	2.85	3	106.0	3.0	106.0
105.0	63.9	190.9	37.7	114.5	407.0	2.83	3	106.0	3.0	106.0
106.0	63.9	192.7	37.7	115.6	409.9	2.81	3	106.0	3.0	106.0
107.0	63.9	194.5	37.7	116.7	412.8	2.79	3	106.0	3.0	106.0
108.0	63.9	196.4	37.7	117.8	415.7	2.77	3	106.0	3.0	106.0
109.0	63.9	198.2	37.7	118.9	418.6	2.75	3	106.0	3.0	106.0
110.0	63.9	200.0	37.7	120.0	421.5	2.73	2	70.7	3.0	106.0
111.0	63.9	201.8	37.7	121.1	424.4	2.71	2	70.7	3.0	106.0
112.0	63.9	203.6	37.7	122.2	427.3	2.70	2	70.7	3.0	106.0
113.0	63.9	205.5	37.7	123.3	430.3	2.68	2	70.7	3.0	106.0
114.0	63.9	207.3	37.7	124.4	433.2	2.66	2	70.7	3.0	106.0
115.0	63.9	209.1	37.7	125.5	436.1	2.64	2	70.7	3.0	106.0
116.0	63.9	210.9	37.7	126.5	439.0	2.62	2	70.7	3.0	106.0
117.0	63.9	212.7	37.7	127.6	441.9	2.61	2	70.7	3.0	106.0
118.0	63.9	214.5	37.7	128.7	444.8	2.59	2	70.7	3.0	106.0
119.0	63.9	216.4	37.7	129.8	447.7	2.57	2	70.7	3.0	106.0
120.0	63.9	218.2	37.7	130.9	450.6	2.56	2	70.7	3.0	106.0

D a i l y C o s t s , V e h i c l e R e q u i r e m e n t s .

DIST	*--------- DAILY COSTS (R)			---------*	*---- DAILY SUMMARY			----*
(km)	FIXED	VARIABLE	ADMIN	TOTAL	VEH	TRIPS	EACH	COST/VEH
100.0	812.56	1070.92	113.01	1996.49	1	3	3.0	1996.49
101.0	812.56	1081.63	113.65	2007.84	1	3	3.0	2007.84
102.0	812.56	1092.34	114.29	2019.19	1	3	3.0	2019.19
103.0	812.56	1103.04	114.94	2030.54	1	3	3.0	2030.54
104.0	812.56	1113.75	115.58	2041.89	1	3	3.0	2041.89
105.0	812.56	1124.46	116.22	2053.25	1	3	3.0	2053.25
106.0	812.56	1135.17	116.86	2064.60	1	3	3.0	2064.60
107.0	812.56	1145.88	117.51	2075.95	1	3	3.0	2075.95
108.0	812.56	1156.59	118.15	2087.30	1	3	3.0	2087.30
109.0	812.56	1167.30	118.79	2098.65	1	3	3.0	2098.65
110.0	812.56	1178.01	119.43	2110.00	1	3	3.0	2110.00
111.0	812.56	1188.72	120.08	2121.36	1	3	3.0	2121.36
112.0	812.56	1199.43	120.72	2132.71	1	3	3.0	2132.71
113.0	812.56	1210.14	121.36	2144.06	1	3	3.0	2144.06
114.0	812.56	1220.85	122.00	2155.41	1	3	3.0	2155.41
115.0	812.56	1231.55	122.65	2166.76	1	3	3.0	2166.76
116.0	812.56	1242.26	123.29	2178.11	1	3	3.0	2178.11
117.0	812.56	1252.97	123.93	2189.47	1	3	3.0	2189.47
118.0	812.56	1263.68	124.57	2200.82	1	3	3.0	2200.82
119.0	812.56	1274.39	125.22	2212.17	1	3	3.0	2212.17
120.0	812.56	1285.10	125.86	2223.52	1	3	3.0	2223.52

LOGTRAN II v1.0 (C) 1991 CSIR

Manager (SAPPI) Forestry Engineering

Lead distance 120.0 km DAILY(*) COSTS ARE PER VEHICLE (1 vehicle)

COSTS PER :	(*)DAY(R)	TON(R)	KM(R)	TRIP(R)	TON/KM(c)
Labour .... :	100.00	0.94	0.14	33.33	0.79
Capital ... :	213.51	2.01	0.30	71.17	1.68
Interest .. :	269.03	2.54	0.37	89.68	2.12
Insurance . :	213.51	2.01	0.30	71.17	1.68
License ... :	16.51	0.16	0.02	5.50	0.13
FIXED .... :	812.56	7.67	1.13	270.85	6.39
Fuel ...... :	644.98	6.09	0.90	214.99	5.07
Oil .... :	16.12	0.15	0.02	5.37	0.13
Tyres ..... :	336.00	3.17	0.47	112.00	2.64
Spares .... :	216.00	2.04	0.30	72.00	1.70
Workshop .. :	72.00	0.68	0.10	24.00	0.57
VARIABLE . :	1285.10	12.12	1.78	428.37	10.10
Admin ..... :	125.86	1.19	0.17	41.95	0.99
TOTAL COST :	2223.52	20.98	3.09	741.17	17.48

LOGTRAN II v1.0 (C) 1991 CSIR

Manager (SAPPI) Forestry Engineering

L O G T R A N   R U N

I n d i v i d u a l   C o s t s   p e r   T O N   (R)

LEAD	*----------	FIXED	----------	*		*--------	VARIABLE		---------*		ADMIN	TOTAL
DIST (km)	LAB	CAP	INT	INS+ LIC	TOTAL	FUEL	OIL	TYRES	SPARE WSHOP	TOTAL	6.00%	
100	0.94	2.01	2.54	2.17	7.67	5.07	0.13	2.64	2.26	10.10	1.07	18.84
101	0.94	2.01	2.54	2.17	7.67	5.12	0.13	2.67	2.29	10.20	1.07	18.94
102	0.94	2.01	2.54	2.17	7.67	5.17	0.13	2.69	2.31	10.31	1.08	19.05
103	0.94	2.01	2.54	2.17	7.67	5.22	0.13	2.72	2.33	10.41	1.08	19.16
104	0.94	2.01	2.54	2.17	7.67	5.27	0.13	2.75	2.35	10.51	1.09	19.26
105	0.94	2.01	2.54	2.17	7.67	5.32	0.13	2.77	2.38	10.61	1.10	19.37
106	0.94	2.01	2.54	2.17	7.67	5.38	0.13	2.80	2.40	10.71	1.10	19.48
107	0.94	2.01	2.54	2.17	7.67	5.43	0.14	2.83	2.42	10.81	1.11	19.59
108	0.94	2.01	2.54	2.17	7.67	5.48	0.14	2.85	2.45	10.91	1.11	19.69
109	0.94	2.01	2.54	2.17	7.67	5.53	0.14	2.88	2.47	11.01	1.12	19.80
110	0.94	2.01	2.54	2.17	7.67	5.58	0.14	2.91	2.49	11.11	1.13	19.91
111	0.94	2.01	2.54	2.17	7.67	5.63	0.14	2.93	2.51	11.22	1.13	20.01
112	0.94	2.01	2.54	2.17	7.67	5.68	0.14	2.96	2.54	11.32	1.14	20.12
113	0.94	2.01	2.54	2.17	7.67	5.73	0.14	2.99	2.56	11.42	1.15	20.23
114	0.94	2.01	2.54	2.17	7.67	5.78	0.14	3.01	2.58	11.52	1.15	20.34
115	0.94	2.01	2.54	2.17	7.67	5.83	0.15	3.04	2.60	11.62	1.16	20.44
116	0.94	2.01	2.54	2.17	7.67	5.88	0.15	3.06	2.63	11.72	1.16	20.55
117	0.94	2.01	2.54	2.17	7.67	5.93	0.15	3.09	2.65	11.82	1.17	20.66
118	0.94	2.01	2.54	2.17	7.67	5.98	0.15	3.12	2.67	11.92	1.18	20.76
119	0.94	2.01	2.54	2.17	7.67	6.03	0.15	3.14	2.69	12.02	1.18	20.87
120	0.94	2.01	2.54	2.17	7.67	6.09	0.15	3.17	2.72	12.12	1.19	20.98

Individual Costs per KILOMETER (R)

LEAD DIST (km)	FIXED LAB	FIXED CAP	FIXED INT	FIXED INS+ LIC	FIXED TOTAL	VARIABLE FUEL	VARIABLE OIL	VARIABLE TYRES	VARIABLE SPARE WSHOP	VARIABLE TOTAL	ADMIN 6.00%	TOTAL
100	0.17	0.36	0.45	0.38	1.35	0.90	0.02	0.47	0.40	1.78	0.19	3.33
101	0.17	0.35	0.44	0.38	1.34	0.90	0.02	0.47	0.40	1.78	0.19	3.31
102	0.16	0.35	0.44	0.38	1.33	0.90	0.02	0.47	0.40	1.78	0.19	3.30
103	0.16	0.35	0.44	0.37	1.31	0.90	0.02	0.47	0.40	1.78	0.19	3.29
104	0.16	0.34	0.43	0.37	1.30	0.90	0.02	0.47	0.40	1.78	0.19	3.27
105	0.16	0.34	0.43	0.37	1.29	0.90	0.02	0.47	0.40	1.78	0.18	3.26
106	0.16	0.34	0.42	0.36	1.28	0.90	0.02	0.47	0.40	1.78	0.18	3.25
107	0.16	0.33	0.42	0.36	1.27	0.90	0.02	0.47	0.40	1.78	0.18	3.23
108	0.15	0.33	0.42	0.35	1.25	0.90	0.02	0.47	0.40	1.78	0.18	3.22
109	0.15	0.33	0.41	0.35	1.24	0.90	0.02	0.47	0.40	1.78	0.18	3.21
110	0.15	0.32	0.41	0.35	1.23	0.90	0.02	0.47	0.40	1.78	0.18	3.20
111	0.15	0.32	0.40	0.35	1.22	0.90	0.02	0.47	0.40	1.78	0.18	3.19
112	0.15	0.32	0.40	0.34	1.21	0.90	0.02	0.47	0.40	1.78	0.18	3.17
113	0.15	0.31	0.40	0.34	1.20	0.90	0.02	0.47	0.40	1.78	0.18	3.16
114	0.15	0.31	0.39	0.34	1.19	0.90	0.02	0.47	0.40	1.78	0.18	3.15
115	0.14	0.31	0.39	0.33	1.18	0.90	0.02	0.47	0.40	1.78	0.18	3.14
116	0.14	0.31	0.39	0.33	1.17	0.90	0.02	0.47	0.40	1.78	0.18	3.13
117	0.14	0.30	0.38	0.33	1.16	0.90	0.02	0.47	0.40	1.78	0.18	3.12
118	0.14	0.30	0.38	0.32	1.15	0.90	0.02	0.47	0.40	1.78	0.18	3.11
119	0.14	0.30	0.38	0.32	1.14	0.90	0.02	0.47	0.40	1.78	0.18	3.10
120	0.14	0.30	0.37	0.32	1.13	0.90	0.02	0.47	0.40	1.78	0.17	3.09

I n d i v i d u a l C o s t s p e r T R I P (R)

LEAD	*---------- FIXED			----------*		*-------- VARIABLE				---------*	ADMIN	TOTAL
DIST (km)	LAB	CAP	INT	INS+ LIC	TOTAL	FUEL	OIL	TYRES	SPARE WSHOP	TOTAL	6.00%	
100	33.33	71.17	89.68	76.67	270.85	179.16	4.48	93.33	80.00	356.97	37.67	665.50
101	33.33	71.17	89.68	76.67	270.85	180.95	4.52	94.27	80.80	360.54	37.88	669.28
102	33.33	71.17	89.68	76.67	270.85	182.74	4.57	95.20	81.60	364.11	38.10	673.06
103	33.33	71.17	89.68	76.67	270.85	184.53	4.61	96.13	82.40	367.68	38.31	676.85
104	33.33	71.17	89.68	76.67	270.85	186.33	4.66	97.07	83.20	371.25	38.53	680.63
105	33.33	71.17	89.68	76.67	270.85	188.12	4.70	98.00	84.00	374.82	38.74	684.42
106	33.33	71.17	89.68	76.67	270.85	189.91	4.75	98.93	84.80	378.39	38.95	688.20
107	33.33	71.17	89.68	76.67	270.85	191.70	4.79	99.87	85.60	381.96	39.17	691.98
108	33.33	71.17	89.68	76.67	270.85	193.49	4.84	100.80	86.40	385.53	39.38	695.77
109	33.33	71.17	89.68	76.67	270.85	195.28	4.88	101.73	87.20	389.10	39.60	699.55
110	33.33	71.17	89.68	76.67	270.85	197.08	4.93	102.67	88.00	392.67	39.81	703.33
111	33.33	71.17	89.68	76.67	270.85	198.87	4.97	103.60	88.80	396.24	40.03	707.12
112	33.33	71.17	89.68	76.67	270.85	200.66	5.02	104.53	89.60	399.81	40.24	710.90
113	33.33	71.17	89.68	76.67	270.85	202.45	5.06	105.47	90.40	403.38	40.45	714.69
114	33.33	71.17	89.68	76.67	270.85	204.24	5.11	106.40	91.20	406.95	40.67	718.47
115	33.33	71.17	89.68	76.67	270.85	206.03	5.15	107.33	92.00	410.52	40.88	722.25
116	33.33	71.17	89.68	76.67	270.85	207.83	5.20	108.27	92.80	414.09	41.10	726.04
117	33.33	71.17	89.68	76.67	270.85	209.62	5.24	109.20	93.60	417.66	41.31	729.82
118	33.33	71.17	89.68	76.67	270.85	211.41	5.29	110.13	94.40	421.23	41.52	733.61
119	33.33	71.17	89.68	76.67	270.85	213.20	5.33	111.07	95.20	424.80	41.74	737.39
120	33.33	71.17	89.68	76.67	270.85	214.99	5.37	112.00	96.00	428.37	41.95	741.17

I n d i v i d u a l C o s t s p e r T O N / K M (c)

LEAD DIST (km)	*---------- FIXED LAB	CAP	INT	INS+ LIC	TOTAL ----------*	*-------- VARIABLE FUEL	OIL	TYRES	SPARE WSHOP	TOTAL ---------*	ADMIN 6.00%	TOTAL
100	0.94	2.01	2.54	2.17	7.67	5.07	0.13	2.64	2.26	10.10	1.07	18.84
101	0.93	1.99	2.51	2.15	7.59	5.07	0.13	2.64	2.26	10.10	1.06	18.76
102	0.92	1.97	2.49	2.13	7.52	5.07	0.13	2.64	2.26	10.10	1.06	18.68
103	0.92	1.96	2.46	2.11	7.44	5.07	0.13	2.64	2.26	10.10	1.05	18.60
104	0.91	1.94	2.44	2.09	7.37	5.07	0.13	2.64	2.26	10.10	1.05	18.52
105	0.90	1.92	2.42	2.07	7.30	5.07	0.13	2.64	2.26	10.10	1.04	18.45
106	0.89	1.90	2.39	2.05	7.23	5.07	0.13	2.64	2.26	10.10	1.04	18.38
107	0.88	1.88	2.37	2.03	7.16	5.07	0.13	2.64	2.26	10.10	1.04	18.30
108	0.87	1.87	2.35	2.01	7.10	5.07	0.13	2.64	2.26	10.10	1.03	18.23
109	0.87	1.85	2.33	1.99	7.03	5.07	0.13	2.64	2.26	10.10	1.03	18.17
110	0.86	1.83	2.31	1.97	6.97	5.07	0.13	2.64	2.26	10.10	1.02	18.10
111	0.85	1.81	2.29	1.96	6.91	5.07	0.13	2.64	2.26	10.10	1.02	18.03
112	0.84	1.80	2.27	1.94	6.84	5.07	0.13	2.64	2.26	10.10	1.02	17.97
113	0.83	1.78	2.25	1.92	6.78	5.07	0.13	2.64	2.26	10.10	1.01	17.90
114	0.83	1.77	2.23	1.90	6.72	5.07	0.13	2.64	2.26	10.10	1.01	17.84
115	0.82	1.75	2.21	1.89	6.67	5.07	0.13	2.64	2.26	10.10	1.01	17.78
116	0.81	1.74	2.19	1.87	6.61	5.07	0.13	2.64	2.26	10.10	1.00	17.72
117	0.81	1.72	2.17	1.85	6.55	5.07	0.13	2.64	2.26	10.10	1.00	17.66
118	0.80	1.71	2.15	1.84	6.50	5.07	0.13	2.64	2.26	10.10	1.00	17.60
119	0.79	1.69	2.13	1.82	6.44	5.07	0.13	2.64	2.26	10.10	0.99	17.54
120	0.79	1.68	2.12	1.81	6.39	5.07	0.13	2.64	2.26	10.10	0.99	17.48

Appendix Four

Species-Density Categories and Density-Payload Calculations

Density decline after felling figures used for the four species-density categories.

Weeks	**E grandis**	E macarthurii	E fastigata	E elata	E nitens	**CTE's**	**A mearnsii**	P patula	P elliotii	P taeda	**Pines**
0	928	1118	1114	1043	1080	1089	1055	1064	1075	1075	1071
1	788	1013	1005	919	1001	985	966	1042	1053	1053	1049
2	752	947	939	858	929	918	915	1031	1053	1053	1045
3	731	904	895	819	872	873	895	990	1053	1031	1025
4	715	873	861	788	832	839	886	980	1053	1020	1018
5	702	848	833	764	804	812	882	962	1042	1020	1008
6	692	829	812	746	784	793	879	943	1020	1000	988
7	684	809	793	732	769	776	878	926	1020	1000	982
8	676	794	778	721	759	763	876	909	1020	990	973
9	670	782	767	712	752	753	872	893	1010	980	961
10	664	772	759	705	747	746	870	885	1000	971	952
11	659	765	753	699	746	741	868	862	1000	962	941
12	654	761	747	696	744	737	866	855	1000	962	939
13	650					734	865				938
14	646					731	864				937
15	643					729	863				936
16	640					727	862				935
17	638					726	861				934
18	636					725	860				933
19	635					724	859				932
20	634					723	858				931
21	633					722	857				930
22	632					721	856				929
23	631					720	855				928
24	630					719	854				927
25	629					718	853				926
26	628					717	852				925

Calculations to determine the influence of average E. grandis density figures, average SVF and configuration bulk volume on payload.

Weeks after felling	E grandis	Conversion factor	Possible payload (tonnes) I (6-12.5)	I (9.2-9.2)	RD (7.5-10.5)	SD (11-5.5)	Payload variance from legal maximum (tonnes) I (6-12.5)	I (9.2-9.2)	RD (7.5-10.5)	SD (11-5.5)
0	928	1.078	71.46	56.06	70.55	56.06	35.36	19.66	33.93	18.16
1	788	1.269	60.68	47.60	59.90	47.60	24.58	11.20	23.28	9.70
2	752	1.330	57.90	45.43	57.17	45.43	21.80	9.03	20.55	7.53
3	731	1.368	56.29	44.16	55.57	44.16	20.19	7.76	18.95	6.26
4	715	1.399	55.06	43.19	54.35	43.19	18.96	6.79	17.73	5.29
5	702	1.425	54.05	42.41	53.37	42.41	17.95	6.01	16.75	4.51
6	692	1.445	53.28	41.80	52.61	41.80	17.18	5.40	15.99	3.90
7	684	1.462	52.67	41.32	52.00	41.32	16.57	4.92	15.38	3.42
8	676	1.479	52.05	40.84	51.39	40.84	15.95	4.44	14.77	2.94
9	670	1.493	51.59	40.47	50.93	40.47	15.49	4.07	14.31	2.57
10	664	1.506	51.13	40.11	50.48	40.11	15.03	3.71	13.86	2.21
11	659	1.517	50.74	39.81	50.10	39.81	14.64	3.41	13.48	1.91
12	654	1.529	50.36	39.51	49.72	39.51	14.26	3.11	13.10	1.61
13	650	1.538	50.05	39.27	49.41	39.27	13.95	2.87	12.79	1.37
14	646	1.548	49.74	39.02	49.11	39.02	13.64	2.62	12.49	1.12
15	643	1.555	49.51	38.84	48.88	38.84	13.41	2.44	12.26	0.94
16	640	1.563	49.28	38.66	48.65	38.66	13.18	2.26	12.03	0.76
17	638	1.567	49.13	38.54	48.50	38.54	13.03	2.14	11.88	0.64
18	636	1.572	48.97	38.42	48.35	38.42	12.87	2.02	11.73	0.52
19	635	1.575	48.90	38.36	48.27	38.36	12.79	1.96	11.65	0.46
20	634	1.577	48.82	38.30	48.20	38.30	12.72	1.90	11.58	0.40
21	633	1.580	48.74	38.24	48.12	38.24	12.64	1.84	11.50	0.34
22	632	1.582	48.66	38.18	48.04	38.18	12.56	1.78	11.42	0.28
23	631	1.585	48.59	38.12	47.97	38.12	12.49	1.72	11.35	0.22
24	630	1.587	48.51	38.06	47.89	38.06	12.41	1.66	11.27	0.16
25	629	1.590	48.43	38.00	47.82	38.00	12.33	1.60	11.20	0.10
26	628	1.592	48.36	37.94	47.74	37.94	12.26	1.54	11.12	0.04

Configuration	SVF	Bulk volume	Payload
I (6-12.5)	0.7	110	36.1
I (9.2-9.2)	0.7	86.3	36.4
RD (7.5-10.5)	0.7	108.6	36.62
SD (11-5.5)	0.7	86.3	37.9

Calculations to determine the influence of reduced E. grandis density figures, average SVF and configuration bulk volume on payload.

Weeks after felling	E grandis	Conversion factor	Possible payload (tonnes)				Payload variance from legal maximum (tonnes)			
			I (6-12.5)	I (9.2-9.2)	RD (7.5-10.5)	SD (11-5.5)	I (6-12.5)	I (9.2-9.2)	RD (7.5-10.5)	SD (11-5.5)
0	835.2	1.197	64.31	50.45	63.49	50.45	28.21	14.05	26.87	12.55
1	709.2	1.410	54.61	42.84	53.91	42.84	18.51	6.44	17.29	4.94
2	676.8	1.478	52.11	40.89	51.45	40.89	16.01	4.49	14.83	2.99
3	657.9	1.520	50.66	39.74	50.01	39.74	14.56	3.34	13.39	1.84
4	643.5	1.554	49.55	38.87	48.92	38.87	13.45	2.47	12.30	0.97
5	631.8	1.583	48.65	38.17	48.03	38.17	12.55	1.77	11.41	0.27
6	622.8	1.606	47.96	37.62	47.35	37.62	11.86	1.22	10.73	-0.28
7	615.6	1.624	47.40	37.19	46.80	37.19	11.30	0.79	10.18	-0.71
8	608.4	1.644	46.85	36.75	46.25	36.75	10.75	0.35	9.63	-1.15
9	603	1.658	46.43	36.43	45.84	36.43	10.33	0.03	9.22	-1.47
10	597.6	1.673	46.02	36.10	45.43	36.10	9.92	-0.30	8.81	-1.80
11	593.1	1.686	45.67	35.83	45.09	35.83	9.57	-0.57	8.47	-2.07
12	588.6	1.699	45.32	35.56	44.75	35.56	9.22	-0.84	8.13	-2.34
13	585	1.709	45.05	35.34	44.47	35.34	8.95	-1.06	7.85	-2.56
14	581.4	1.720	44.77	35.12	44.20	35.12	8.67	-1.28	7.58	-2.78
15	578.7	1.728	44.56	34.96	43.99	34.96	8.46	-1.44	7.37	-2.94
16	576	1.736	44.35	34.80	43.79	34.80	8.25	-1.60	7.17	-3.10
17	574.2	1.742	44.21	34.69	43.65	34.69	8.11	-1.71	7.03	-3.21
18	572.4	1.747	44.07	34.58	43.51	34.58	7.97	-1.82	6.89	-3.32
19	571.5	1.750	44.01	34.52	43.45	34.52	7.91	-1.88	6.83	-3.38
20	570.6	1.753	43.94	34.47	43.38	34.47	7.84	-1.93	6.76	-3.43
21	569.7	1.755	43.87	34.42	43.31	34.42	7.77	-1.98	6.69	-3.48
22	568.8	1.758	43.80	34.36	43.24	34.36	7.70	-2.04	6.62	-3.54
23	567.9	1.761	43.73	34.31	43.17	34.31	7.63	-2.09	6.55	-3.59
24	567	1.764	43.66	34.25	43.10	34.25	7.56	-2.15	6.48	-3.65
25	566.1	1.766	43.59	34.20	43.03	34.20	7.49	-2.20	6.41	-3.70
26	565.2	1.769	43.52	34.14	42.97	34.14	7.42	-2.26	6.35	-3.76

Configuration	SVF	Bulk volume	Payload
I (6-12.5)	0.7	110	36.1
I (9.2-9.2)	0.7	86.3	36.4
RD (7.5-10.5)	0.7	108.6	36.62
SD (11-5.5)	0.7	86.3	37.9

Calculations to determine the influence of average E. grandis density figures, reduced SVF and configuration bulk volume on payload.

Weeks after felling	E grandis	Conversion factor	Possible payload (tonnes) I (6-12.5)	I (9.2-9.2)	RD (7.5-10.5)	SD (11-5.5)	Payload variance from legal maximum (tonnes) I (6-12.5)	I (9.2-9.2)	RD (7.5-10.5)	SD (11-5.5)
0	928	1.078	61.25	48.05	60.47	48.05	25.15	11.65	23.85	10.15
1	788	1.269	52.01	40.80	51.35	40.80	15.91	4.40	14.73	2.90
2	752	1.330	49.63	38.94	49.00	38.94	13.53	2.54	12.38	1.04
3	731	1.368	48.25	37.85	47.63	37.85	12.15	1.45	11.01	-0.05
4	715	1.399	47.19	37.02	46.59	37.02	11.09	0.62	9.97	-0.88
5	702	1.425	46.33	36.35	45.74	36.35	10.23	-0.05	9.12	-1.55
6	692	1.445	45.67	35.83	45.09	35.83	9.57	-0.57	8.47	-2.07
7	684	1.462	45.14	35.42	44.57	35.42	9.04	-0.98	7.95	-2.48
8	676	1.479	44.62	35.00	44.05	35.00	8.52	-1.40	7.43	-2.90
9	670	1.493	44.22	34.69	43.66	34.69	8.12	-1.71	7.04	-3.21
10	664	1.506	43.82	34.38	43.27	34.38	7.72	-2.02	6.65	-3.52
11	659	1.517	43.49	34.12	42.94	34.12	7.39	-2.28	6.32	-3.78
12	654	1.529	43.16	33.86	42.61	33.86	7.06	-2.54	5.99	-4.04
13	650	1.538	42.90	33.66	42.35	33.66	6.80	-2.74	5.73	-4.24
14	646	1.548	42.64	33.45	42.09	33.45	6.54	-2.95	5.47	-4.45
15	643	1.555	42.44	33.29	41.90	33.29	6.34	-3.11	5.28	-4.61
16	640	1.563	42.24	33.14	41.70	33.14	6.14	-3.26	5.08	-4.76
17	638	1.567	42.11	33.04	41.57	33.04	6.01	-3.36	4.95	-4.86
18	636	1.572	41.98	32.93	41.44	32.93	5.88	-3.47	4.82	-4.97
19	635	1.575	41.91	32.88	41.38	32.88	5.81	-3.52	4.76	-5.02
20	634	1.577	41.84	32.83	41.31	32.83	5.74	-3.57	4.69	-5.07
21	633	1.580	41.78	32.78	41.25	32.78	5.68	-3.62	4.63	-5.12
22	632	1.582	41.71	32.72	41.18	32.72	5.61	-3.68	4.56	-5.18
23	631	1.585	41.65	32.67	41.12	32.67	5.55	-3.73	4.50	-5.23
24	630	1.587	41.58	32.62	41.05	32.62	5.48	-3.78	4.43	-5.28
25	629	1.590	41.51	32.57	40.99	32.57	5.41	-3.83	4.37	-5.33
26	628	1.592	41.45	32.52	40.92	32.52	5.35	-3.88	4.30	-5.38

Configuration	SVF	Bulk volume	Payload
I (6-12.5)	0.6	110	36.1
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